UJCC

日英気候共同研究

UK-Japan Climate Collaboration

HiGEM

Frontiers of UK climate modelling: resolving processes and scale interactions.

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S. Emori, A. Hasegawa (NIES, Japan)
K. Oouchi (FRCGC, Japan)
W. Yanase (CCSR Tokyo)
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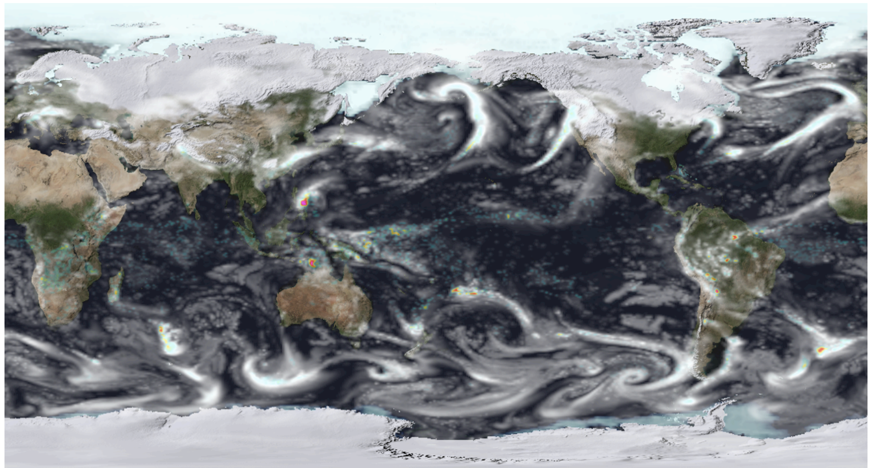

Twin Tropical Cyclones in NUGAM

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Outline

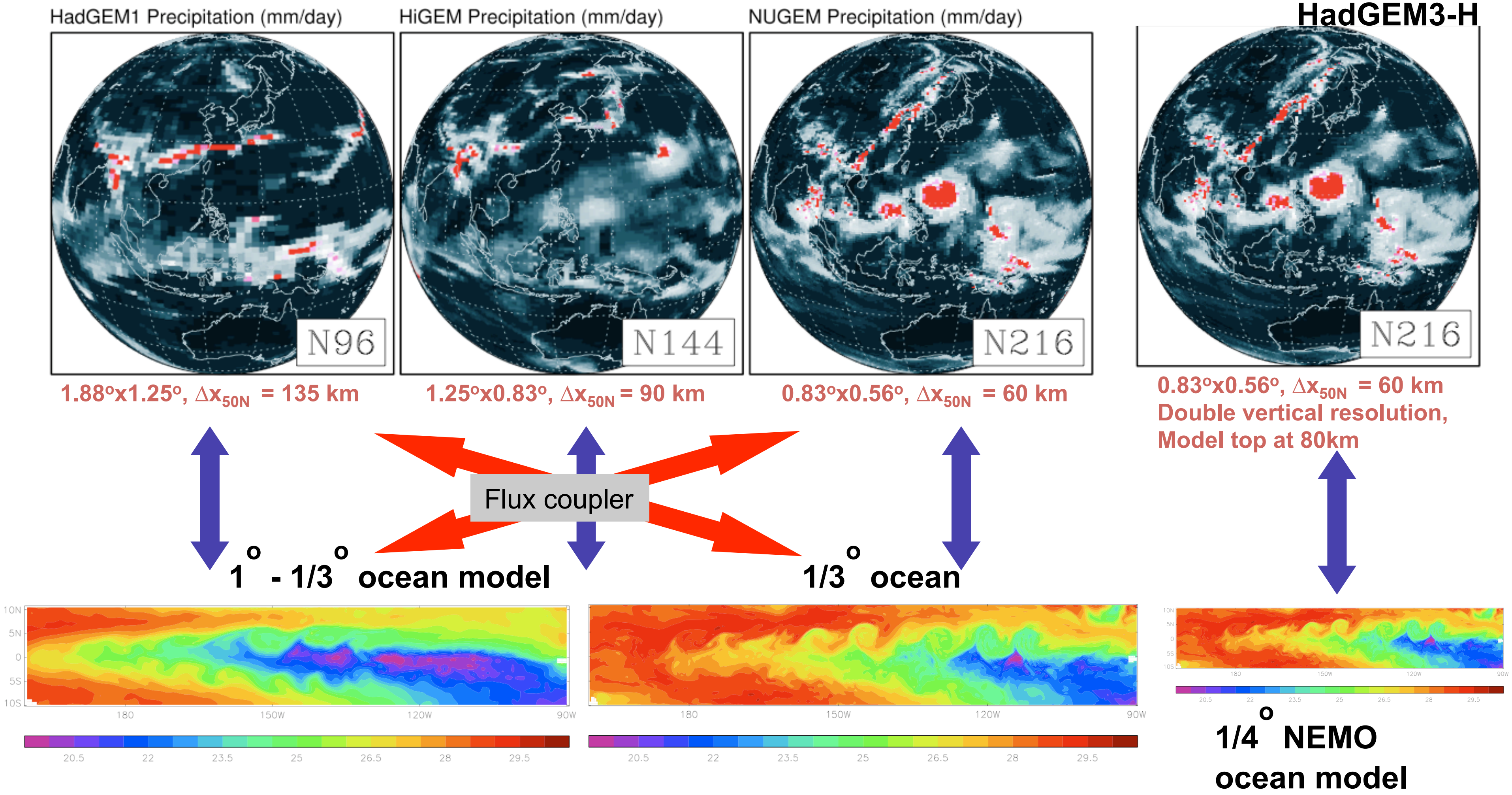
- UK high-resolution global climate models: past and future developments
- The role of resolution:
  - Energy and water cycle considerations
  - High-impact precipitation
- The role of resolution: emerging processes and interactions
  - Tropical and extra-tropical cyclones
  - Tropical Instability Waves
  - ENSO

Frontiers of model development:
High-resolution Climate Modelling

P.L. Vidale, L. Shaffrey, M. Roberts, M.E. Demory, J. Strachan

GCMs developed within HiGEM-UJCC programmes, 2003-2009

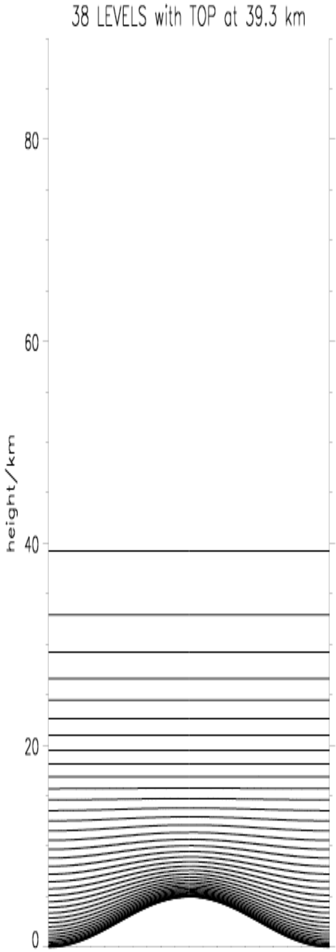
GCMs developed within JRP, 2009-



MO-JCRP AGCMs: Unified Levels

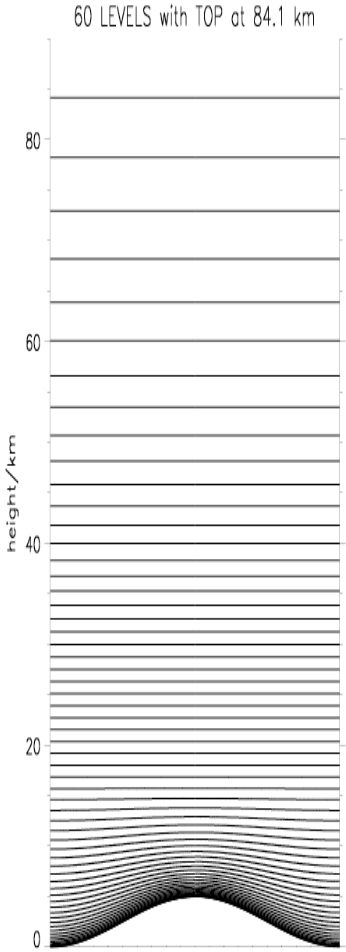
HadGEM1, HiGEM1

$L38(29_t,9_s)_{40}$



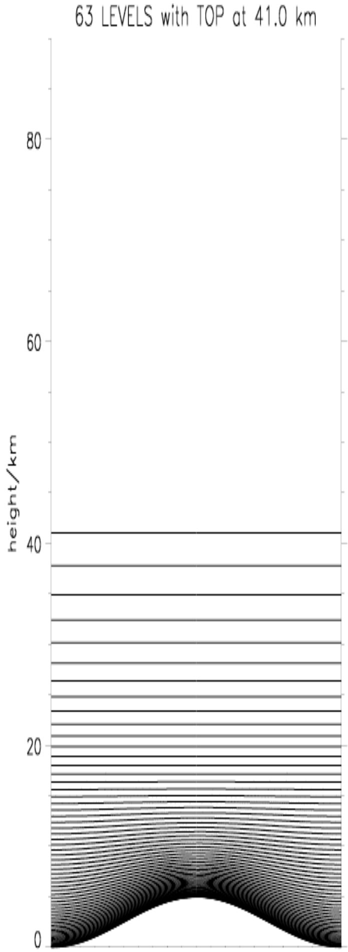
UKCA

$L60(29_t,31_s)_{85}$



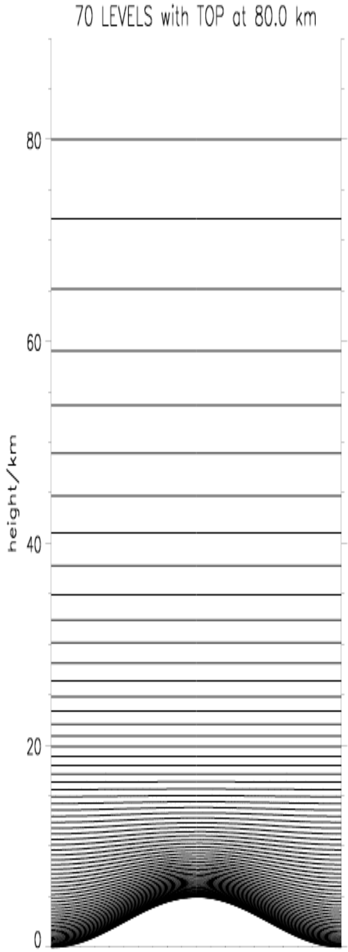
HadGEM3

$L63(50_t,13_s)_{40}$



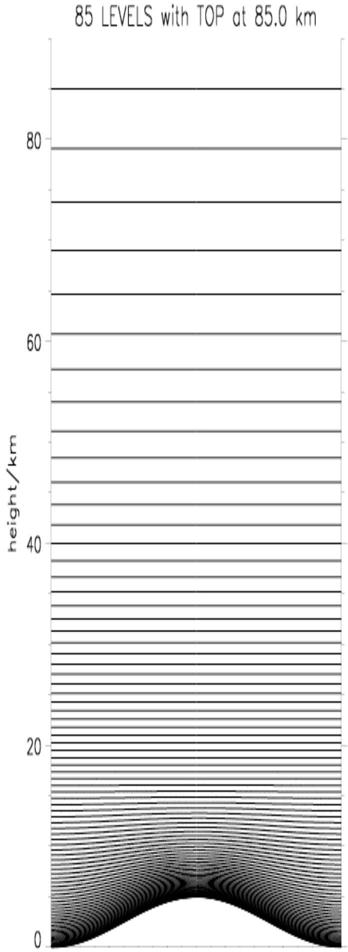
NWP

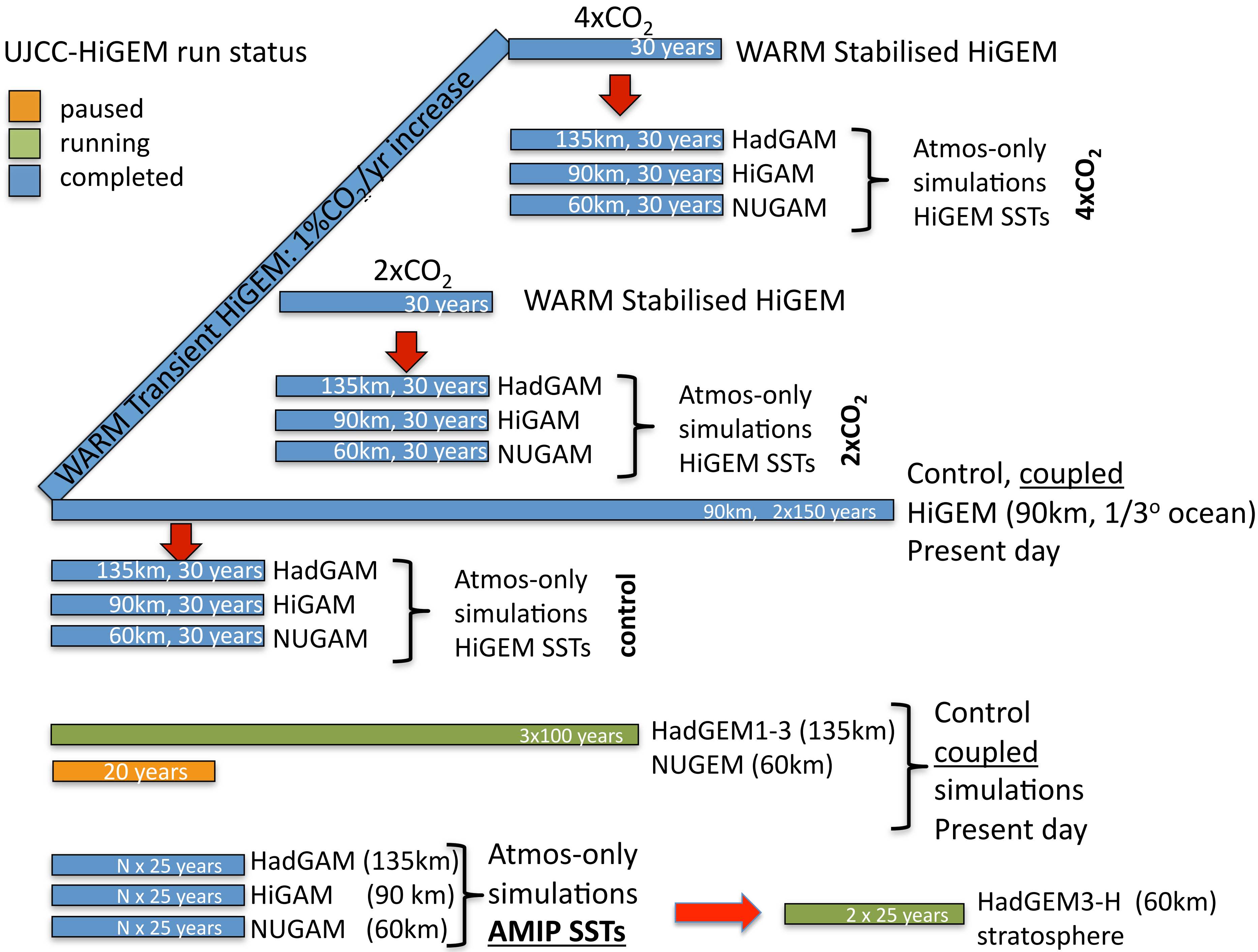
$L70(50_t,20_s)_{80}$



HadGEM3-H

$L85(50_t,35_s)_{85}$




UJCC-HiGEM run status
paused
running
completed
WARM Transient HiGEM: 1%CO2/yr increase
4xCO2
30 years
WARM Stabilised HiGEM
135km, 30 years
HadGAM
90km, 30 years
HiGAM
60km, 30 years
NUGAM
Atmos-only simulations HiGEM SSTs
4xCO2
2xCO2
30 years
WARM Stabilised HiGEM
135km, 30 years
HadGAM
90km, 30 years
HiGAM
60km, 30 years
NUGAM
Atmos-only simulations HiGEM SSTs
2xCO2
90km, 2x150 years
Control, coupled HiGEM (90km, 1/3° ocean) Present day
135km, 30 years
HadGAM
90km, 30 years
HiGAM
60km, 30 years
NUGAM
Atmos-only simulations HiGEM SSTs
control
3x100 years
HadGEM1-3 (135km)
20 years
NUGEM (60km)
Control coupled simulations Present day
N x 25 years
HadGAM (135km)
N x 25 years
HiGAM (90 km)
N x 25 years
NUGAM (60km)
Atmos-only simulations AMIP SSTs
2 x 25 years
HadGEM3-H (60km) stratosphere

Global mean radiation budget

		HadGAM at N48	HadGAM (N96)	HiGAM (N144)	NUGAM (N216)	NUGAM + N96 orography	ERA-interim (P. Berrisford)	Trenberth et al. (2009)
Global	net surface radiation	110	110	111	111	111	108	98
	SH	18	17	18	18	18	17	17
	LH	91	92	91	91	91	83	80
Land	net surface radiation	22	27	23	23	23	21	
	SH	9	9	9	9	10	8	
	LH	12	16	13	13	13	13	
Ocean	net surface radiation	87	83	88	88	88	87	
	SH	9	8	9	9	8	9	
	LH	79	76	78	78	78	70	

Yearly mean of averaged global radiation in W/m2 (fluxes are positive downwards).
Models are based on 24-year climatology, ERA-interim on twice daily 12 forecast data.

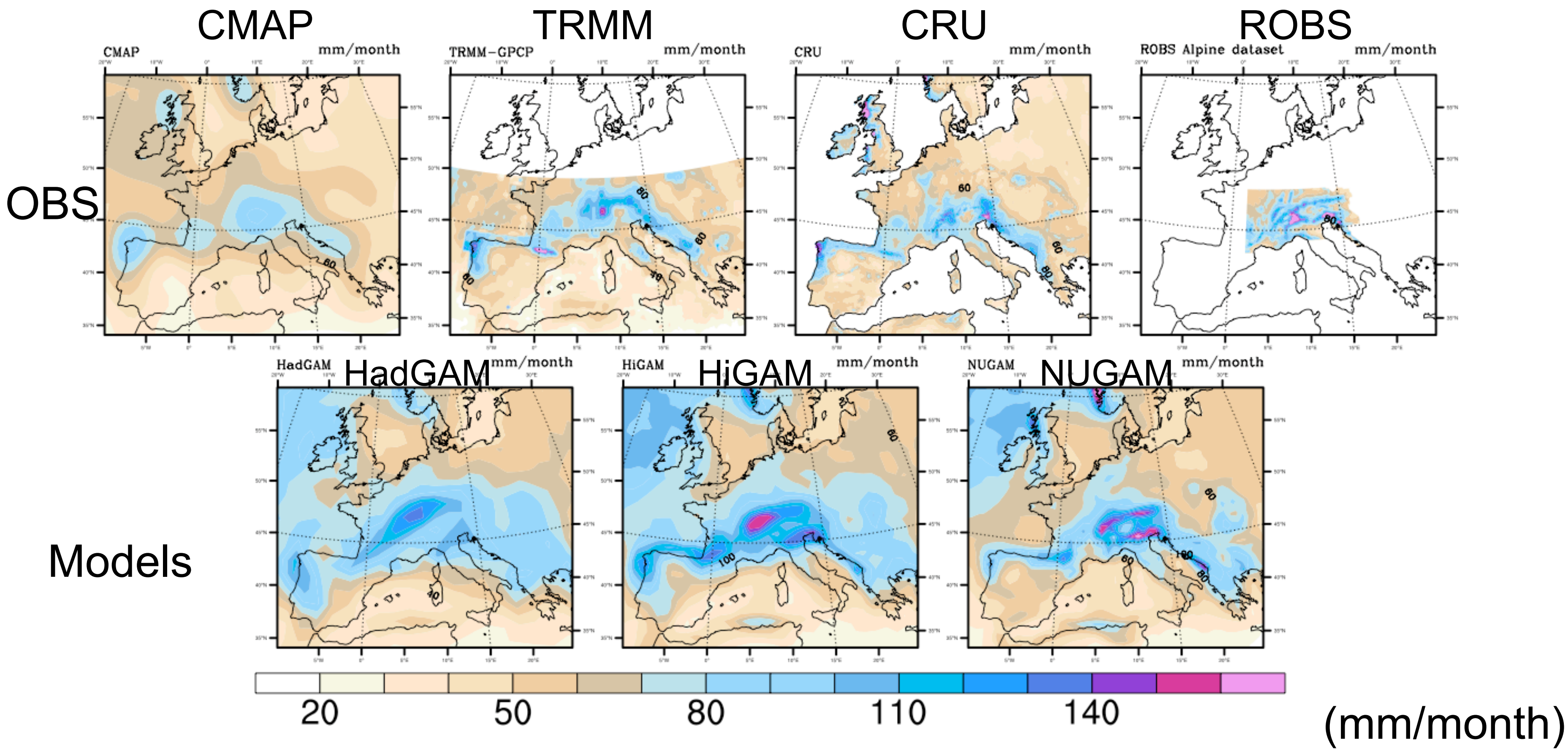
Marie-Estelle Demory and Pier Luigi Vidale

Global mean evaporation, precipitation

1 mm/day = 28.9 Wm^{-2}

		HadGAM at N48	HadGAM (N96)	HiGAM (N144)	NUGAM (N216)	NUGAM + N96 orography	ERA-interim (P. Berrisford)	Trenberth et al. (2007)
Global	Precipitation	3.13	3.17	3.15	3.15	3.15	2.9	2.61
	Evaporation	3.13	3.17	3.15	3.15	3.15	2.9	2.61
Land	Precipitation	0.58	0.74	0.66	0.70	0.68	0.67	0.61
	Evaporation	0.41	0.53	0.44	0.44	0.44	0.44	0.39
	Evaporation to Precipitation ratio	71%	72%	67%	63%	65%	66%	64%
Ocean	Precipitation	2.55	2.43	2.49	2.45	2.46	2.20	2.00
	Evaporation	2.72	2.64	2.71	2.71	2.71	2.41	2.22

Spring in Europe: mean precipitation in our Global Climate Models



- Poor distribution of precipitation maxima in HadGAM and HiGAM
- Better spatial distribution in NUGAM (compared to special, high-density Alpine precipitation dataset)
  - Dry shadow over the mountains well represented in NUGAM
  - Experiments with degraded orography have revealed that transport of moisture is the main mechanism
- Crucial skill in modelling impacts, e.g. river flow, agricultural crops, etc.

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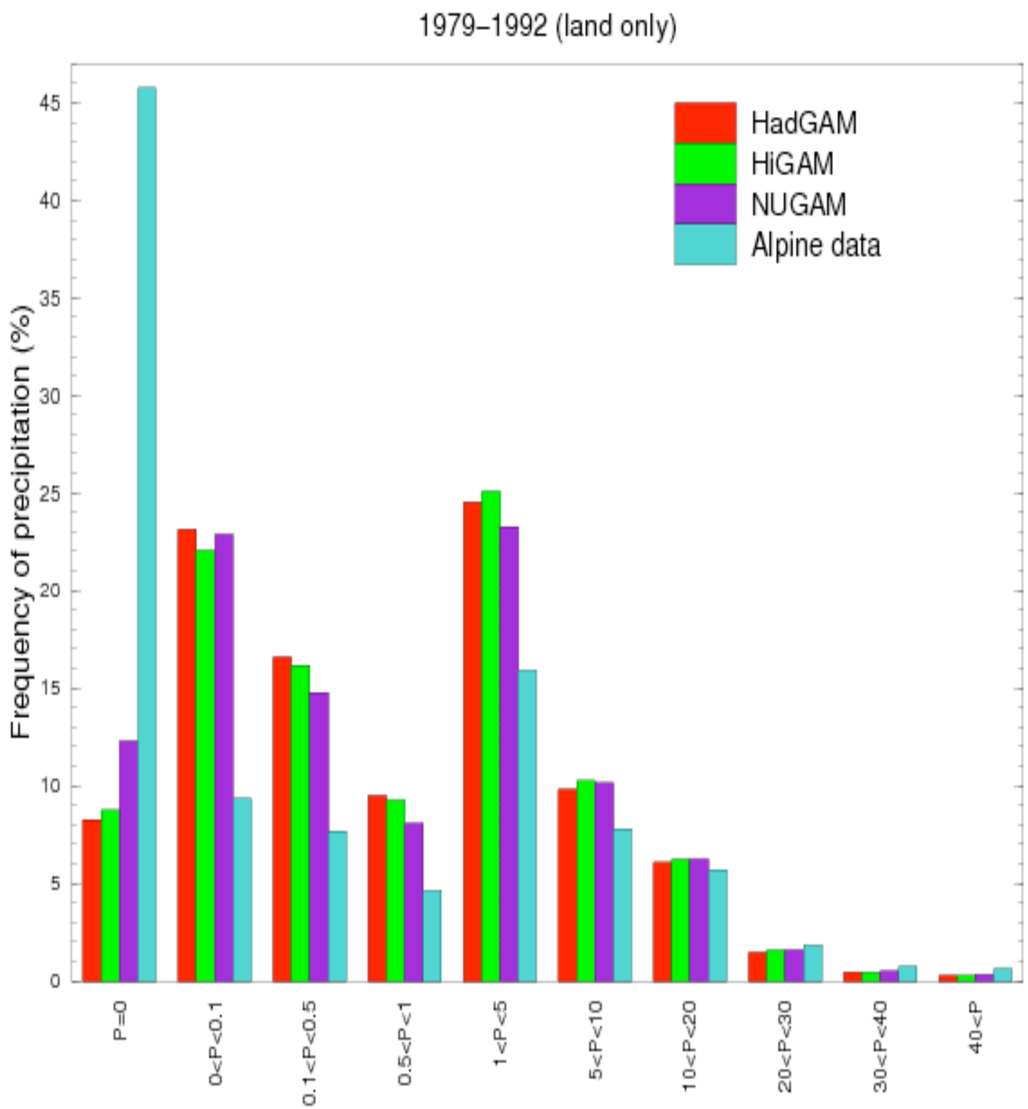
Precipitation frequency-intensity relationship over the Alps

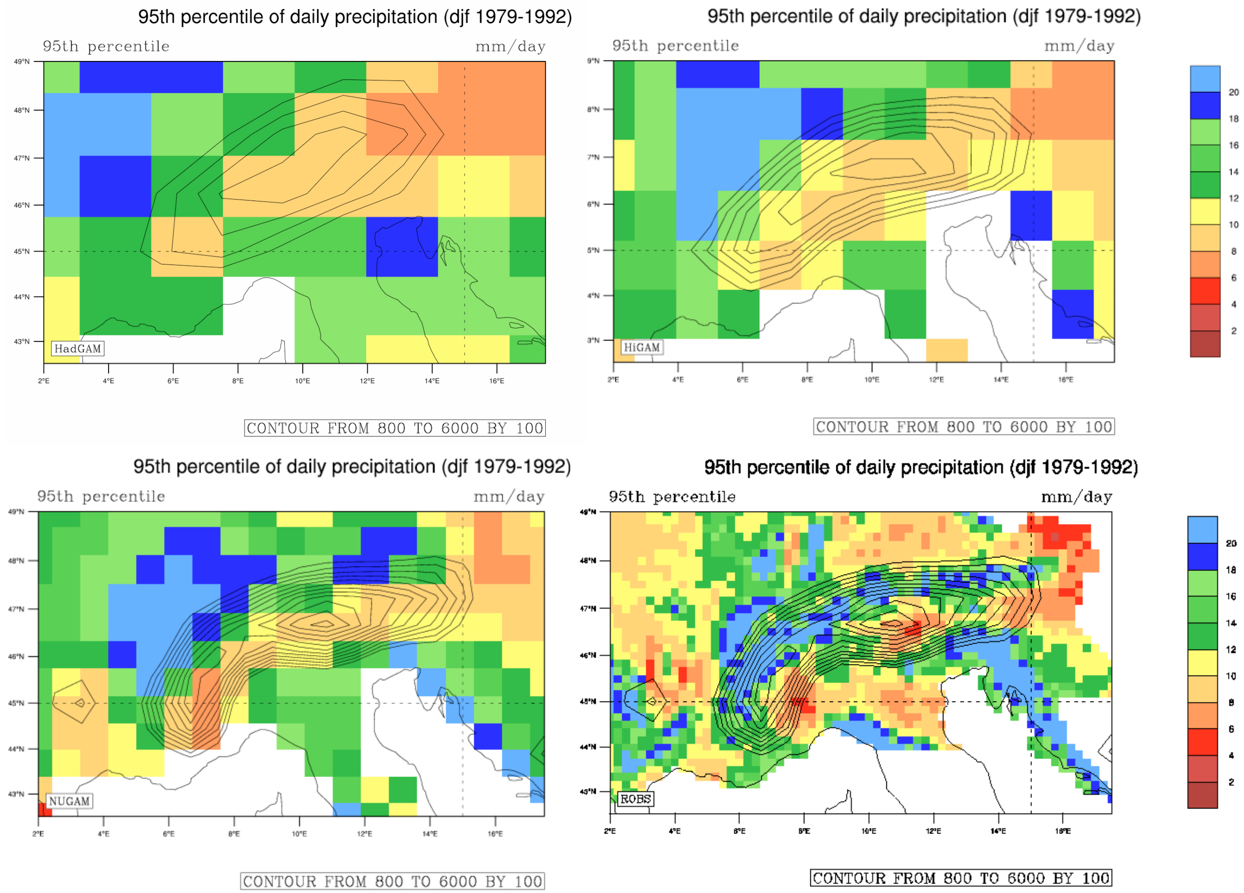


- Compared to the Alpine dataset (C. Frei, Meteoswiss), 6000 stations, daily data over 100 years
- The models simulate too much drizzle precipitation and too few dry events
- Little improvement from using higher resolution in this region
- Part of the reason for the poor land surface-atmosphere coupling strength

Marie-Estelle Demory and Pier Luigi Vidale

High-impact (extreme) precipitation: where can we expect flash floods?

95th percentile of precipitation in European winter



- Better representation of the location of high-impact events in NUGAM GCM (coastline, dry shadow)
- Better representation of scales relevant for river catchment work.
- Crucial modelling capability for hydrological impacts studies, normally only possible with Regional Climate Models.

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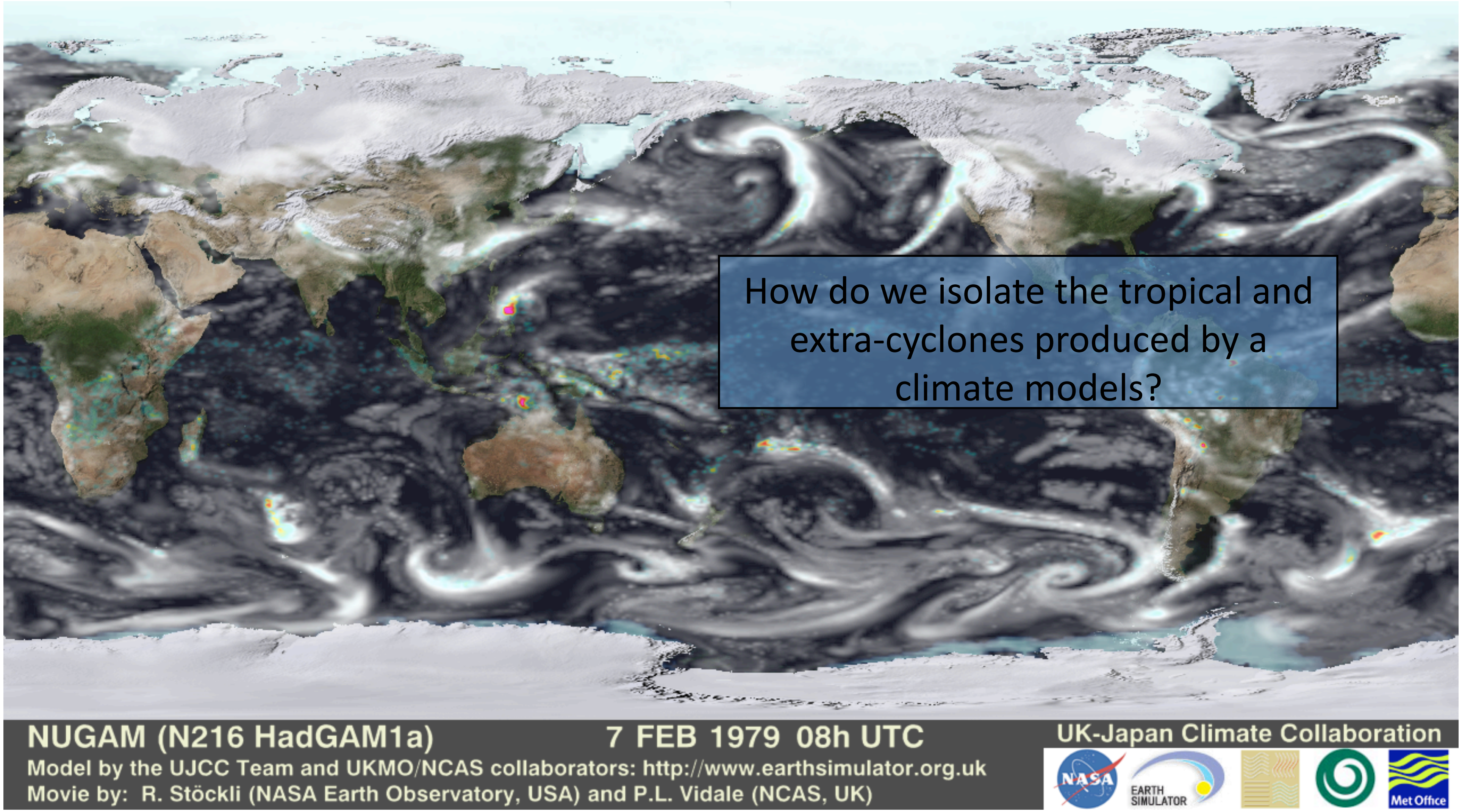
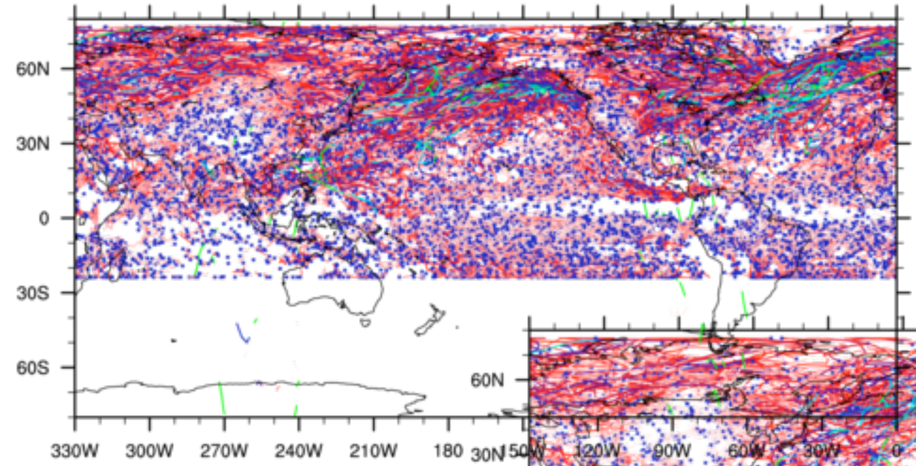
Storms in climate models

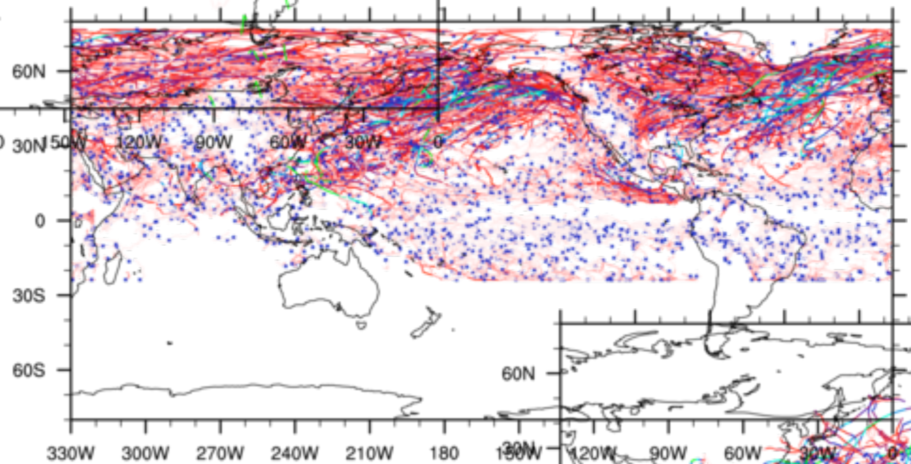


Finding the real tropical cyclones

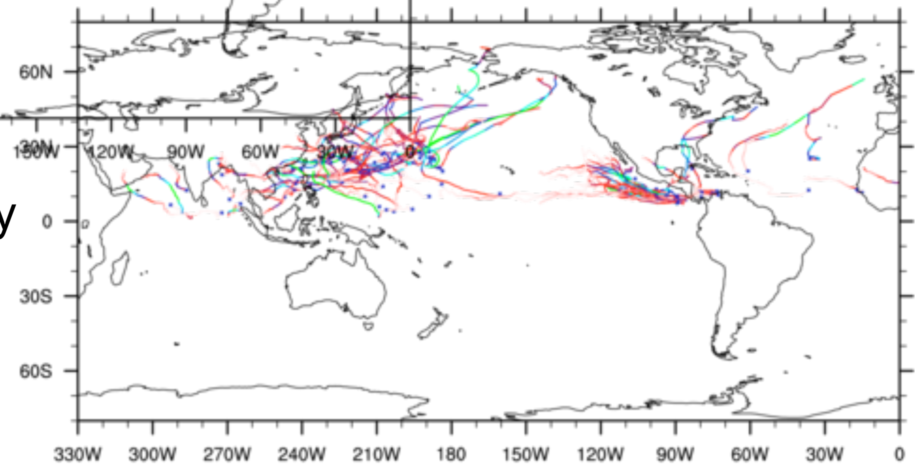
Using a **feature tracking methodology** developed at Reading University by Kevin Hodges



Locate and track centres of high vorticity



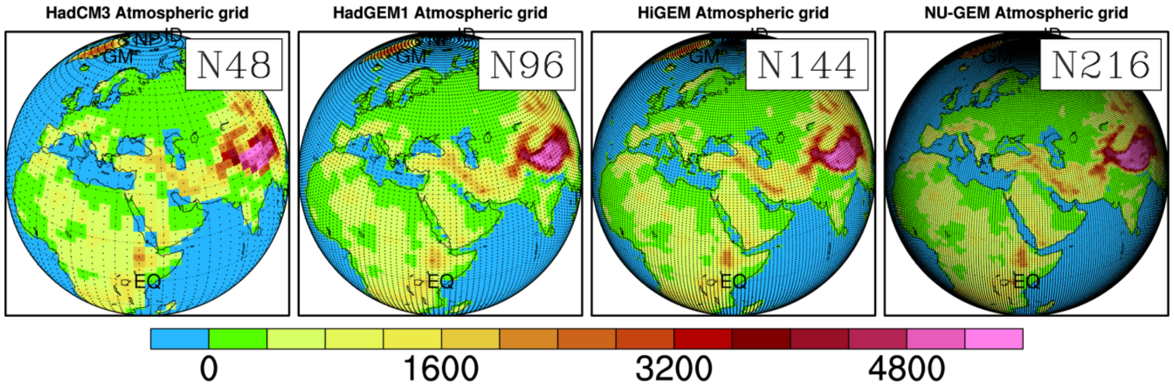
Eliminate tracks with a lifetime of less than 2 days



Accept tracks only if they have the correct vertical structure (warm core)

What resolution is good enough?

Increasing resolution of the UKMO Hadley Centre Global Climate Model



HadCM3 HadGEM HiGEM NUGEM

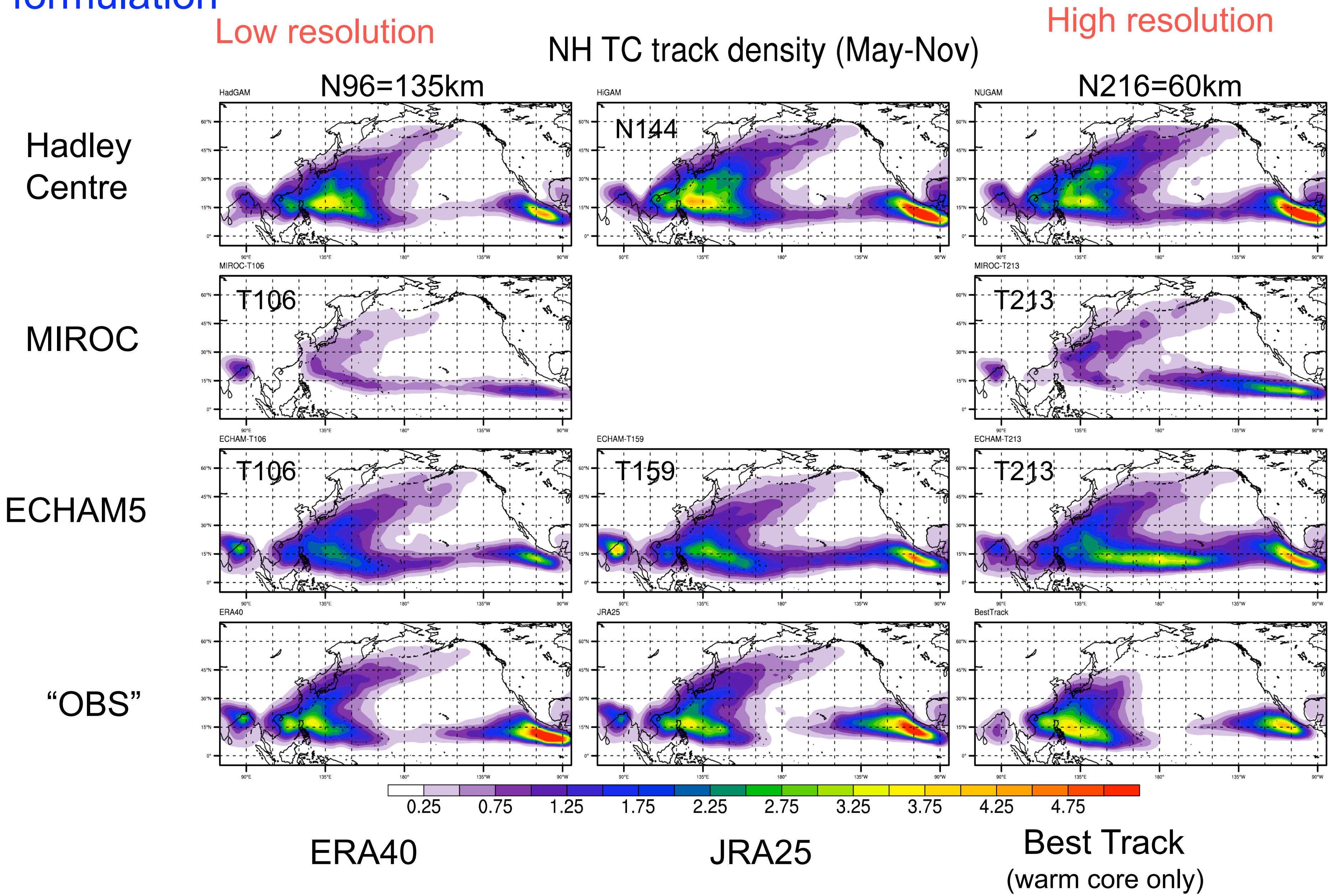
Model spatial resolution

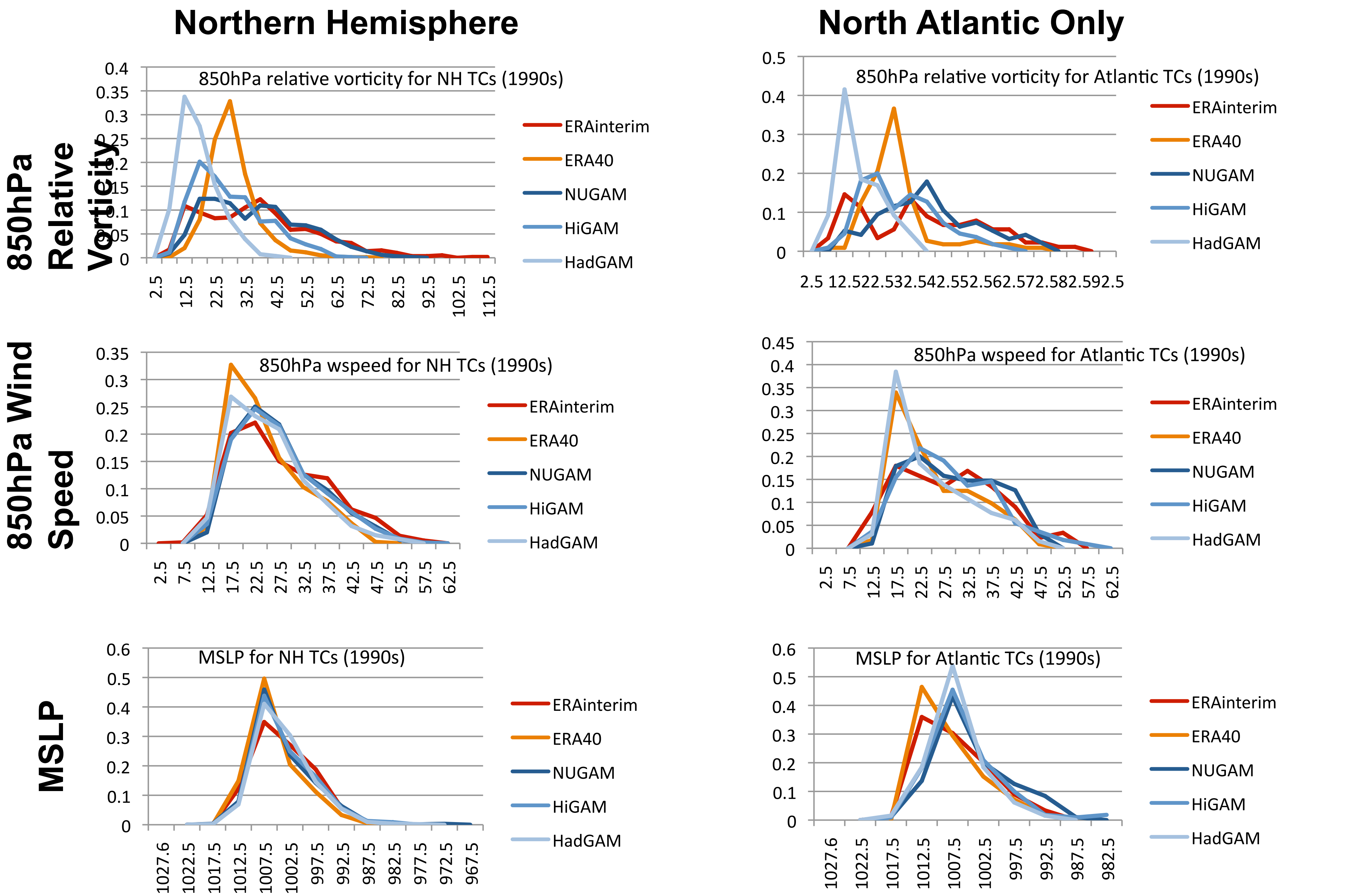
Example from studying Tropical Cyclones:
Location? Frequency? Intensity?

Simulation length (sample size)

The climate modellers dilemma:
1)Spatial resolution
2)Model domain
3)Model complexity
4)Simulation length

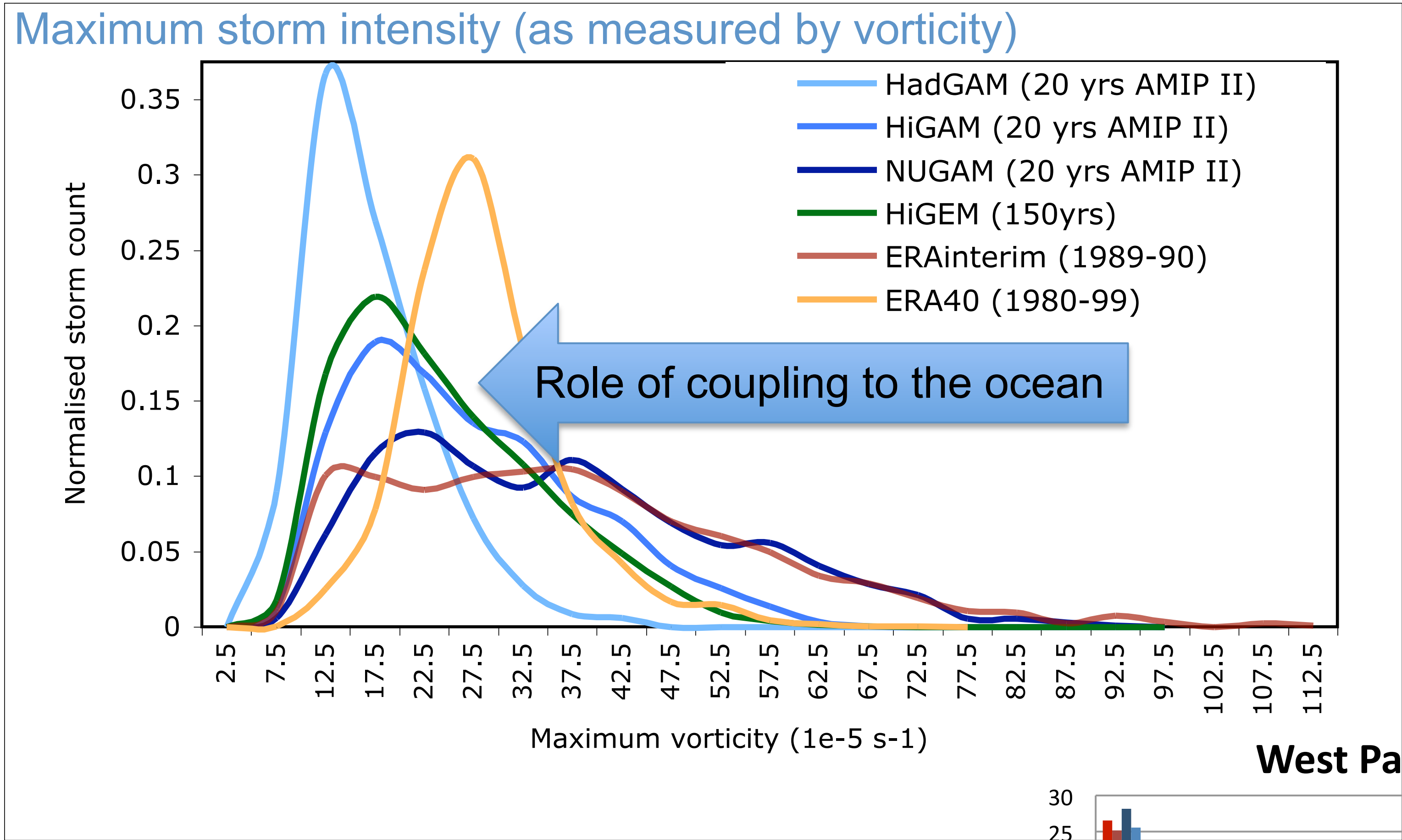
Statistics of Tropical Cyclones in integrations with identical, imposed Sea Surface Temperatures (25 years AMIP2): roles of resolution and formulation

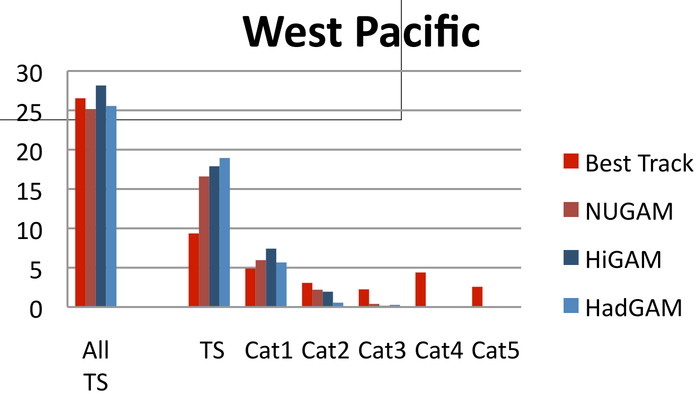




Northern Hemisphere
North Atlantic Only
850hPa Relative Vorticity
850hPa Wind Speed
MSLP
850hPa relative vorticity for NH TCs (1990s)
850hPa relative vorticity for Atlantic TCs (1990s)
850hPa wspeed for NH TCs (1990s)
850hPa wspeed for Atlantic TCs (1990s)
MSLP for NH TCs (1990s)
MSLP for Atlantic TCs (1990s)
ERAinterim
ERA40
NUGAM
HiGAM
HadGAM

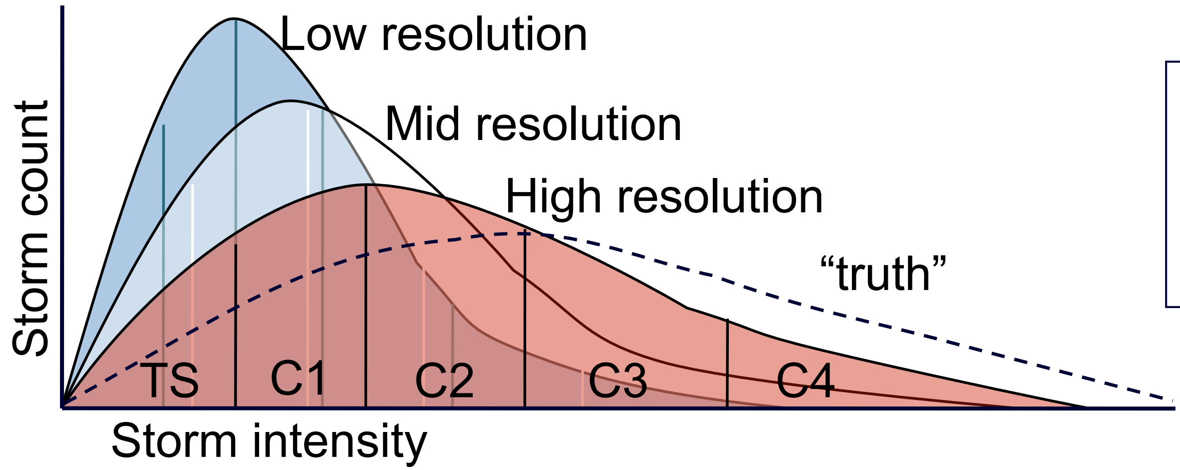
Do dynamically modelled tropical cyclones simulate the correct intensity?





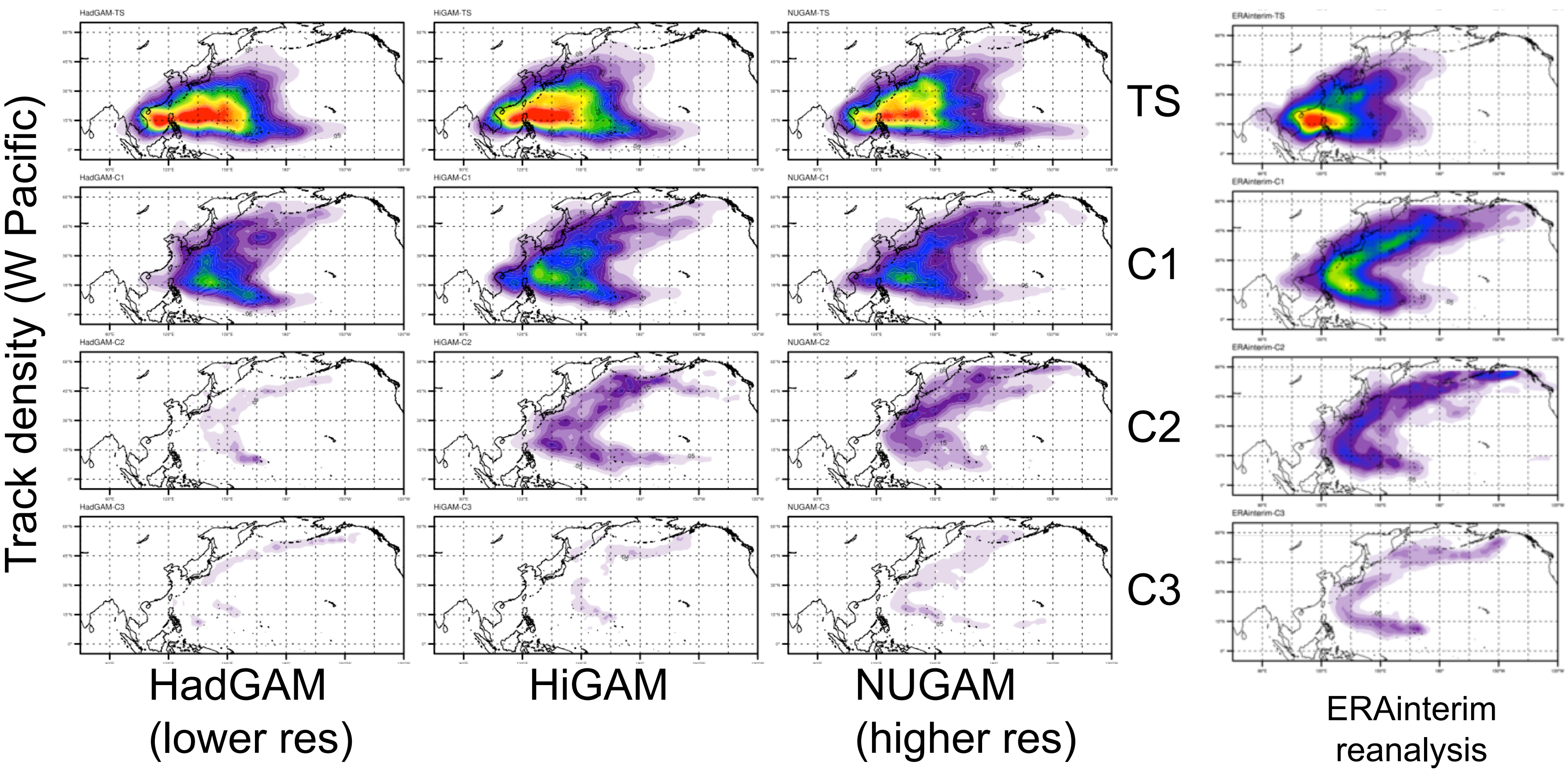
Tropical cyclone intensity
in global climate models and re-analyses

Geographical distribution of storms with respect to storm intensity

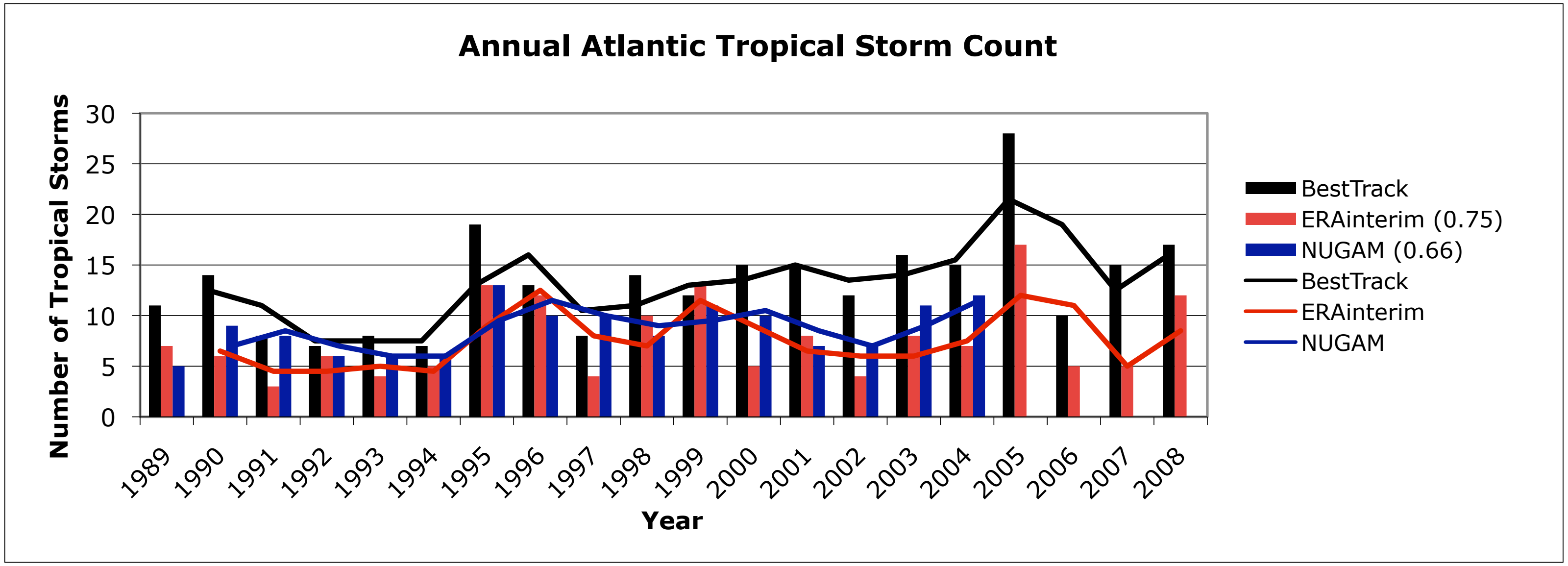


Intensity bias correction would need to take into account::

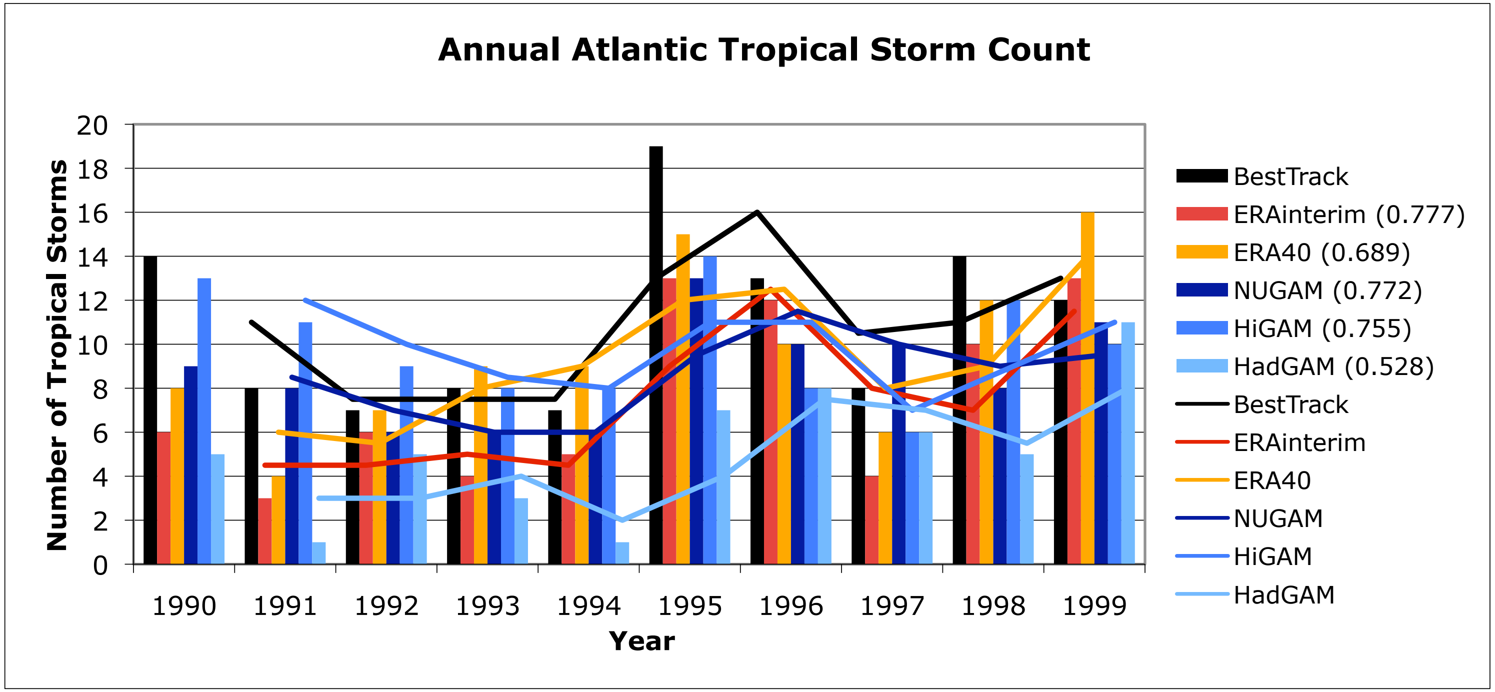
1) Temporal sampling
2) Resolution
3) Height

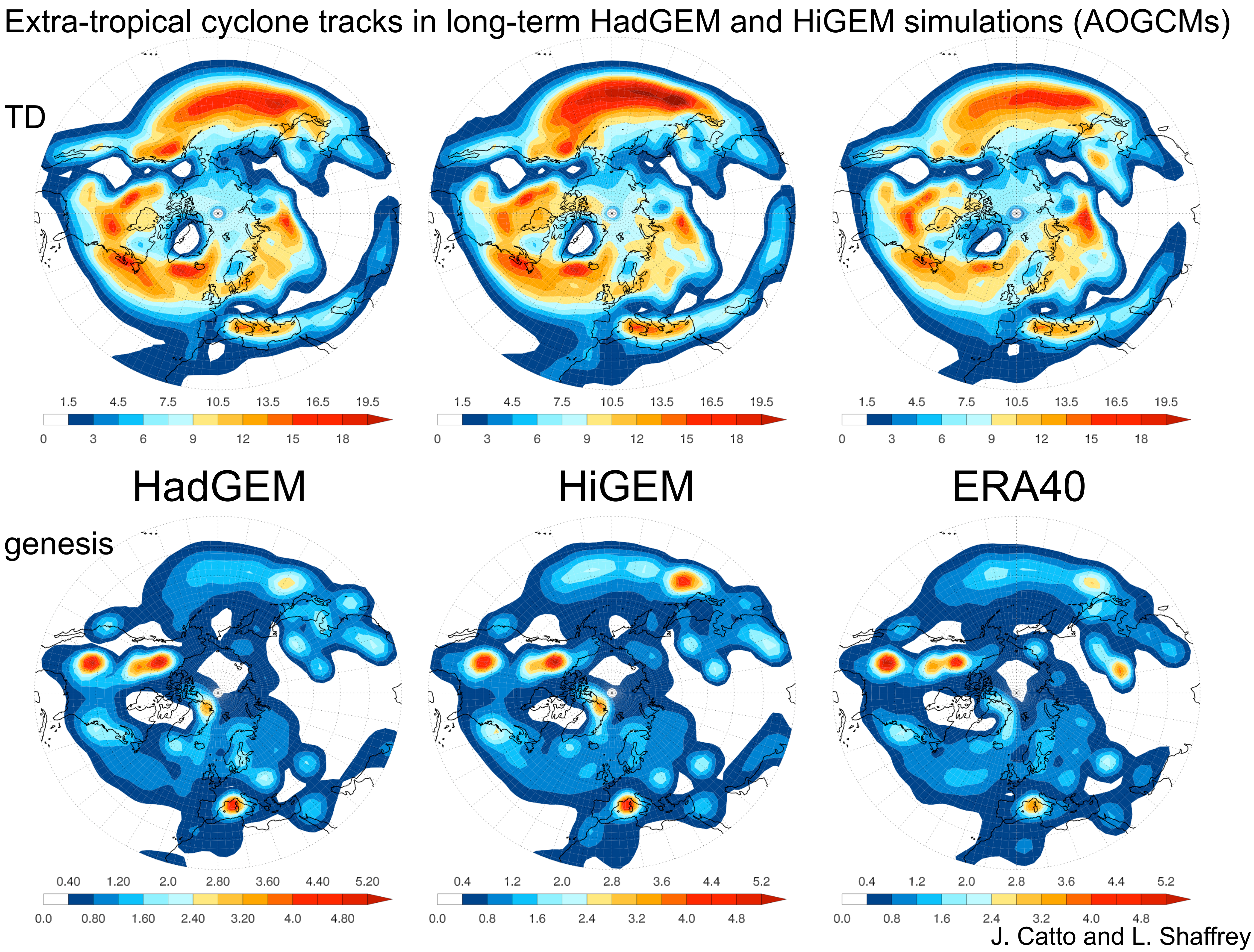


In 1989-2004, correlations with BT: HadGAM= 0.16; HiGAM=0.54 NUGAM=0.66



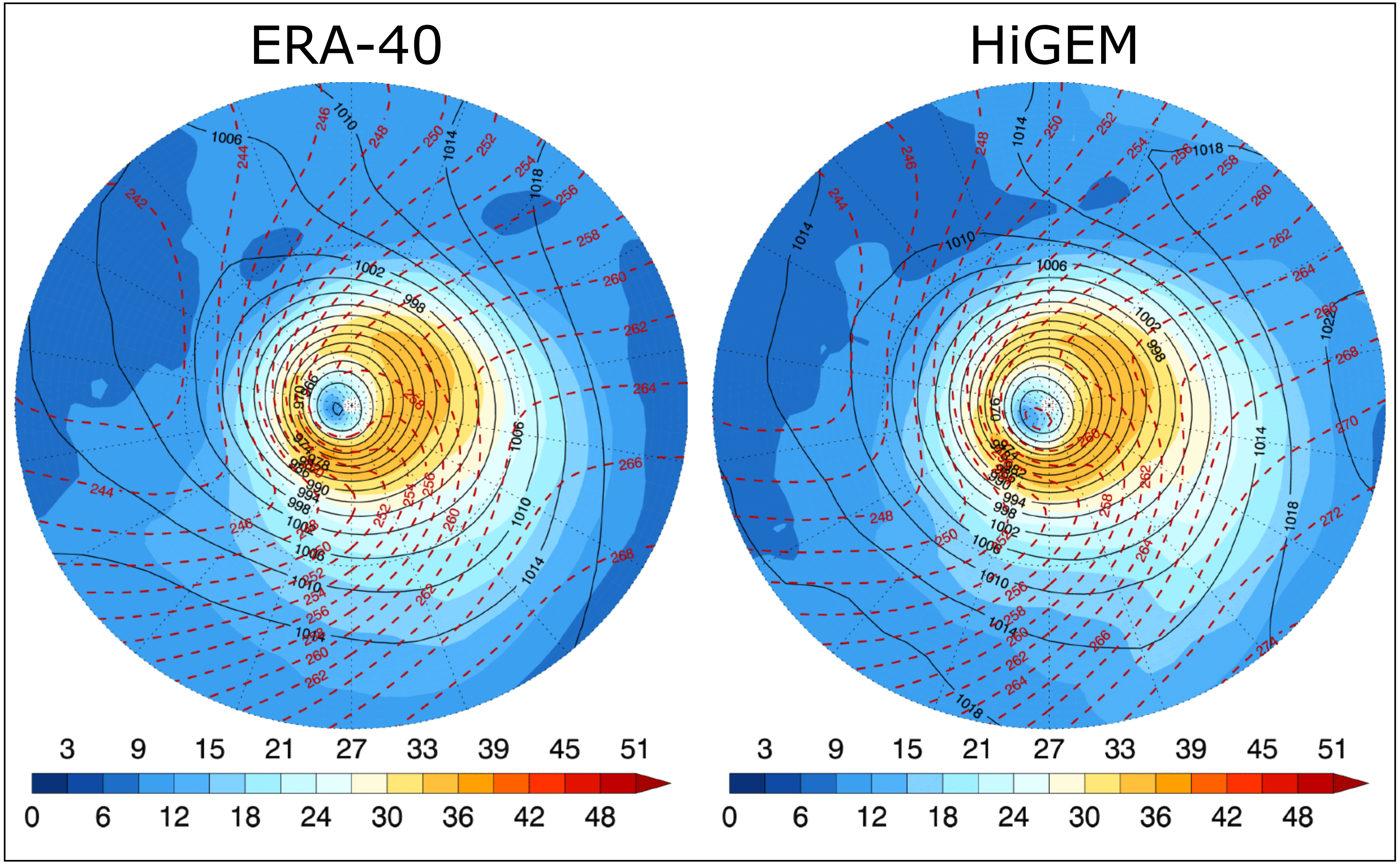
In 1990-1999, including ERA40 and ERAInterim





Extra-tropical cyclone tracks in long-term HadGEM and HiGEM simulations (AOGCMs)
TD
1.5 4.5 7.5 10.5 13.5 16.5 19.5
0 3 6 9 12 15 18
HadGEM
HiGEM
ERA40
genesis
0.40 1.20 2.0 2.80 3.60 4.40 5.20
0.0 0.80 1.60 2.40 3.20 4.0 4.80
0.4 1.2 2.0 2.8 3.6 4.4 5.2
0.0 0.8 1.6 2.4 3.2 4.0 4.8
J. Catto and L. Shaffrey

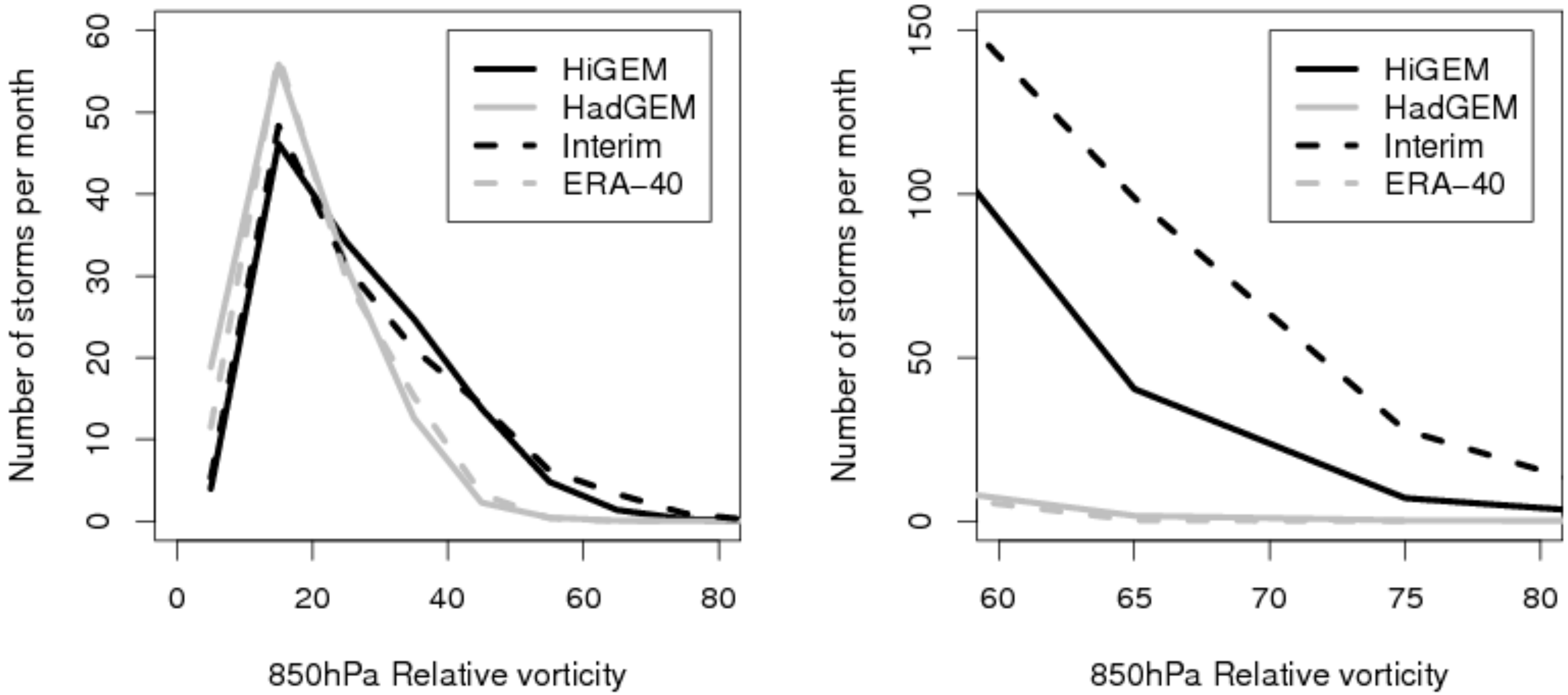
Composite structure of the 50 most extreme wintertime Northern Hemisphere storms in ERA-40 and HiGEM



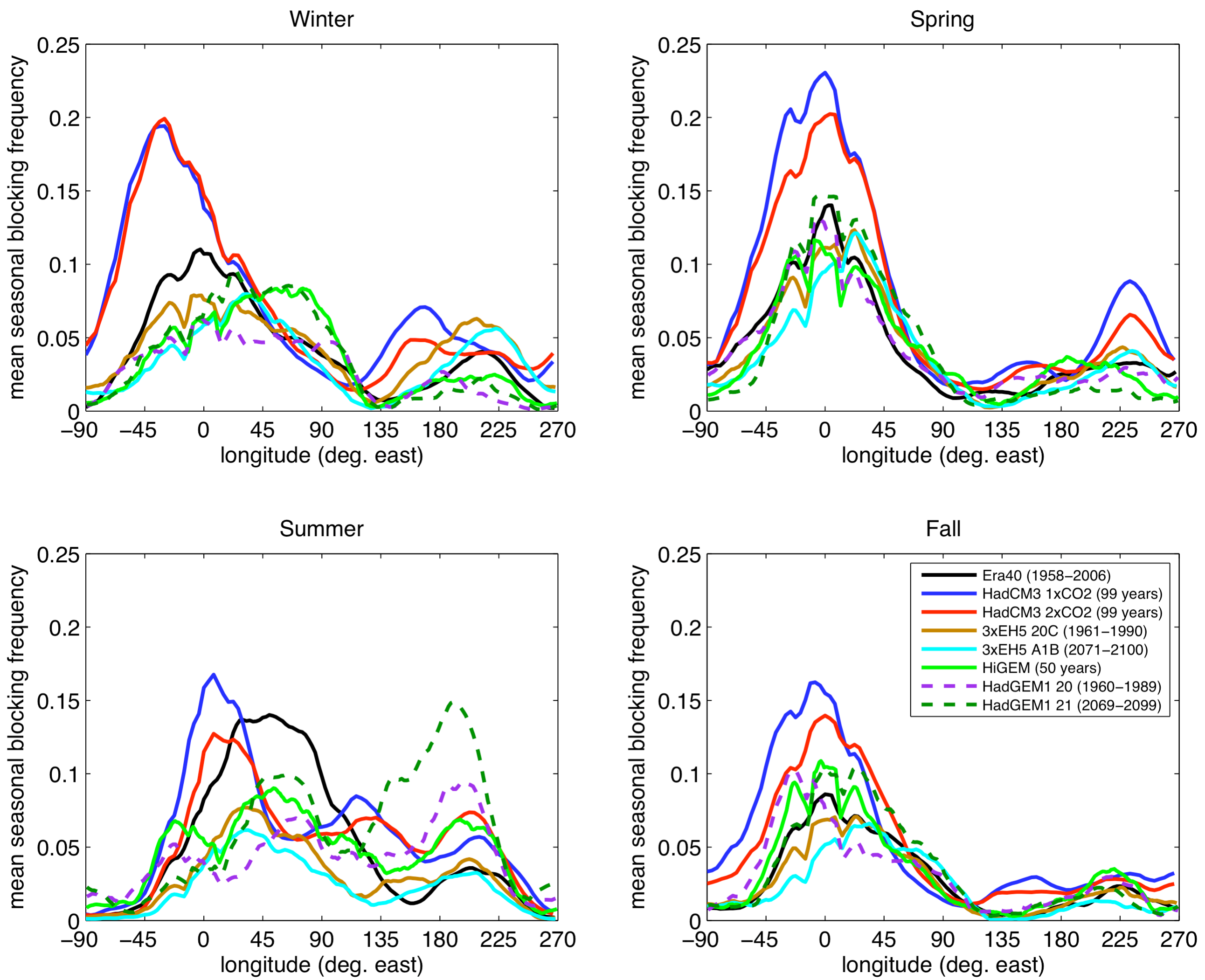
Colours – windspeed, Black lines – 1000hPa isobars, Red lines – 850hPa to 500hPa temperature thickness

Courtesy of Jen Catto

Storm intensity

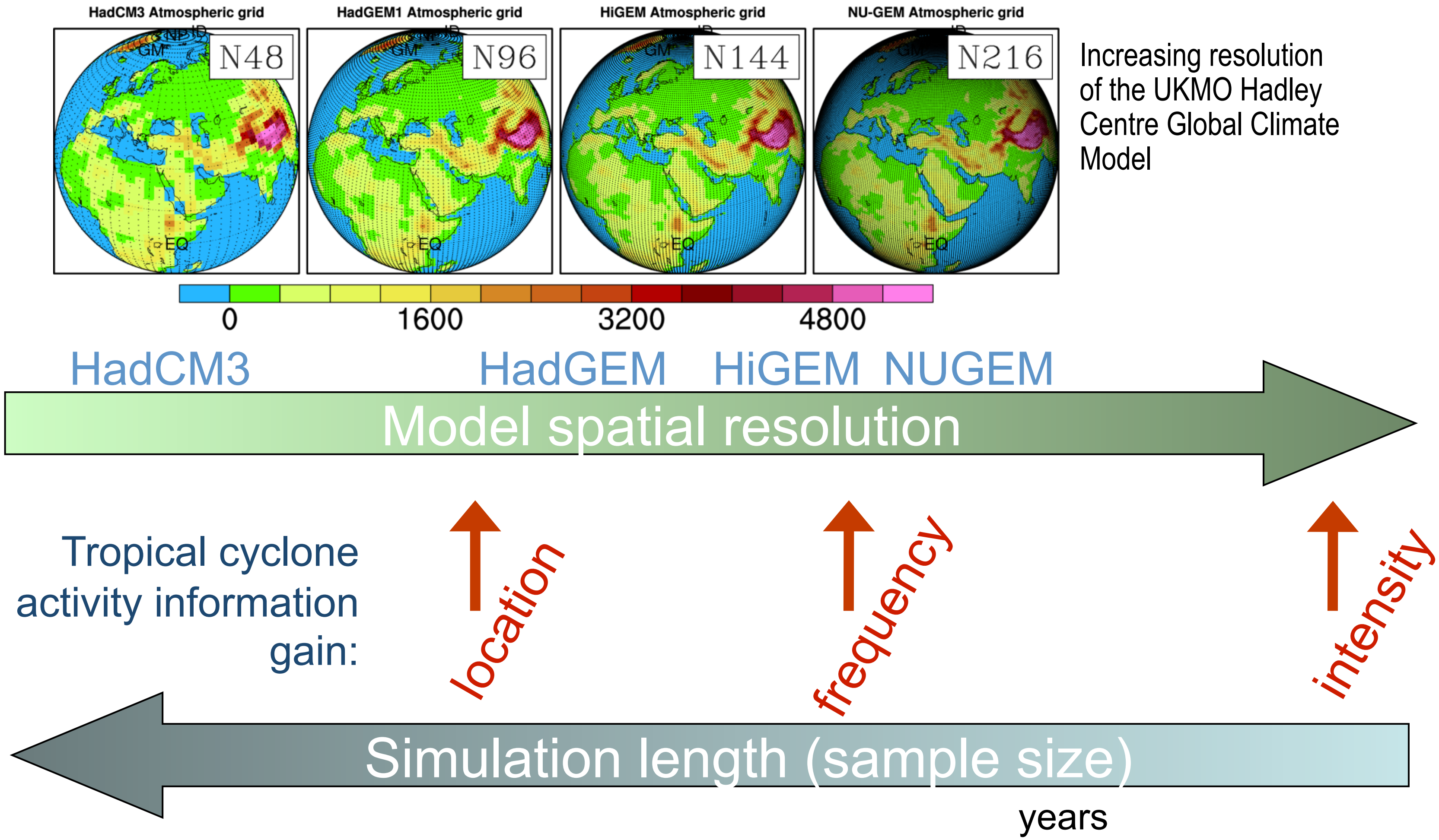


Blocking



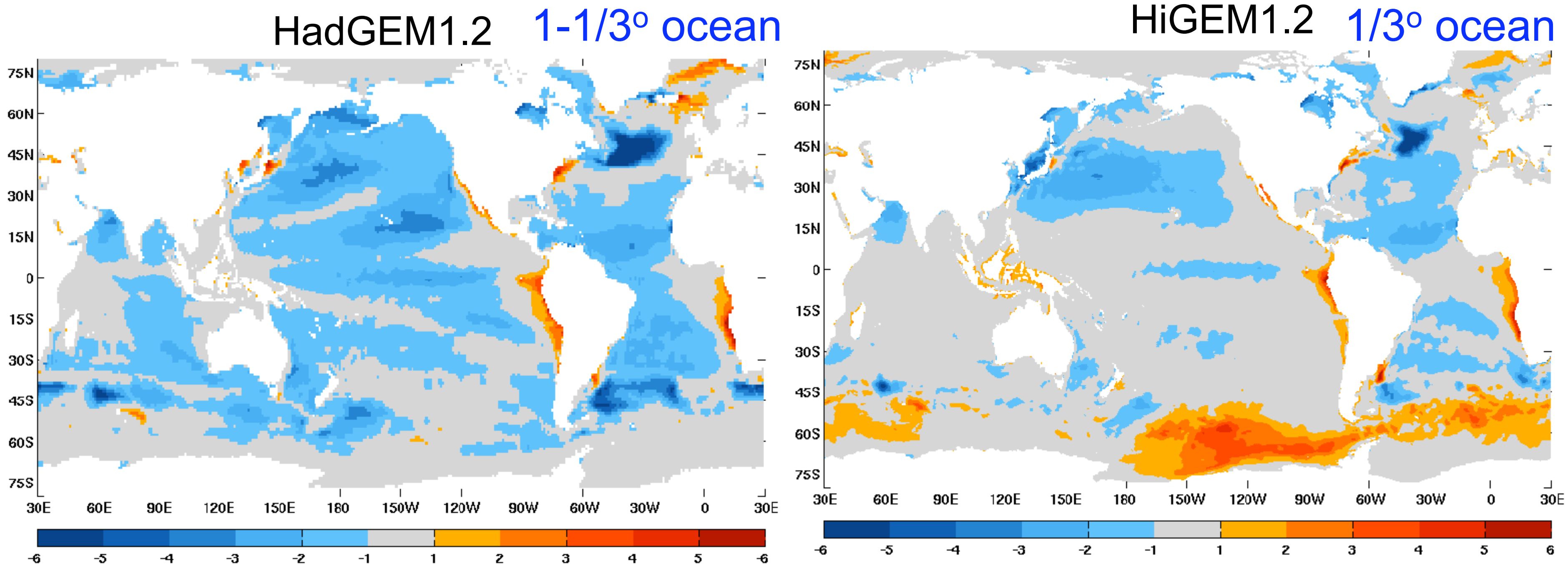
L. Barnes

What resolution is good enough?



HadGEM and HiGEM SSTs

- HadGEM1 SSTs present a fairly substantial cold bias, still present at 1.2
- Improvement in HiGEM is especially important in the tropical Pacific
- The net TOA radiative flux for HiGEM1.2=0.67Wm^{-2} (into the climate system)

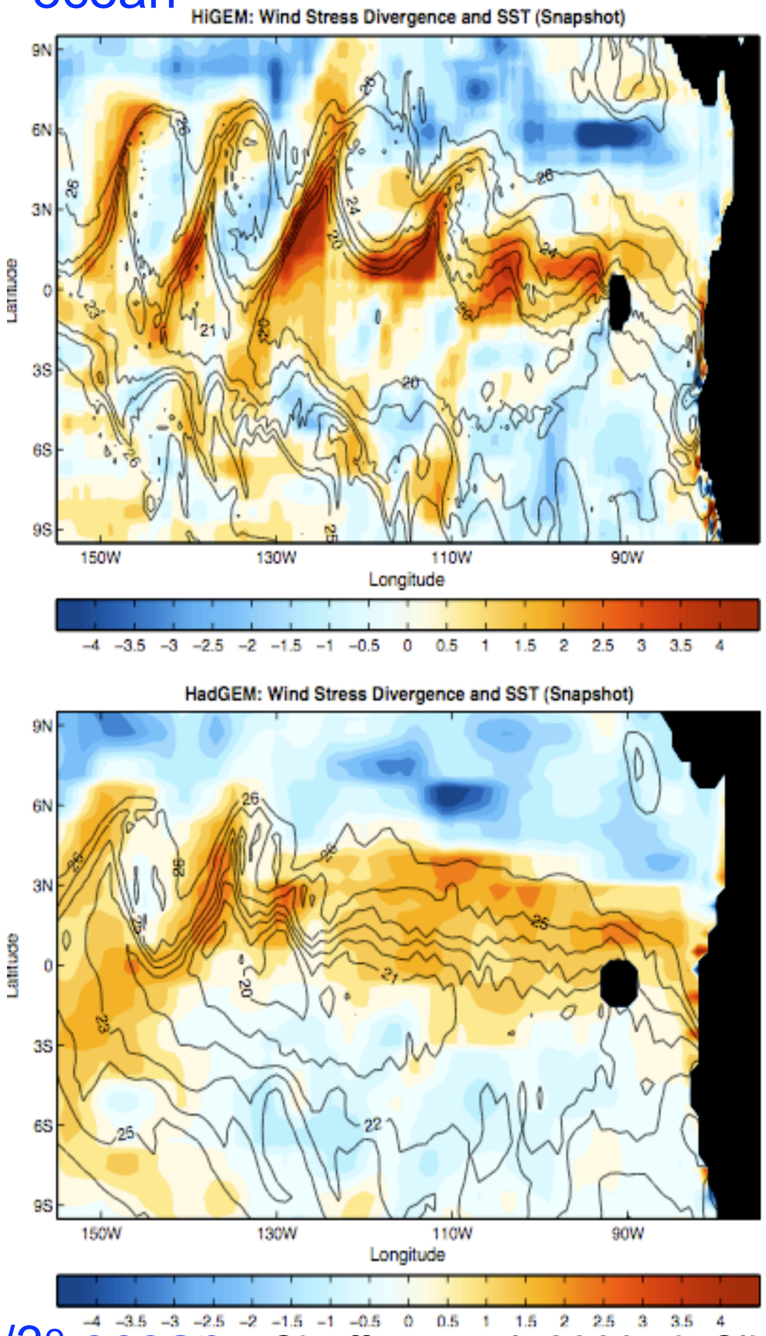


50 year annual mean HadGEM1.2 and HiGEM1.2 SST errors relative to Reynolds SSTs. Units K

Tropical instability waves

- Tropical Instability Waves in the Tropical Pacific Ocean are shear instabilities that grow in the equatorial current-counter current system
  - They propagate slowly westwards (~0.5ms^{-1})
- Resolved in HiGEM, poorly resolved in HadGEM;
- Responsible for meridional heat transport in the tropical Pacific
- Invoked for explaining improved mean state in that region of the ocean, important for El Niño
- See papers by M. Roberts and J. Harle

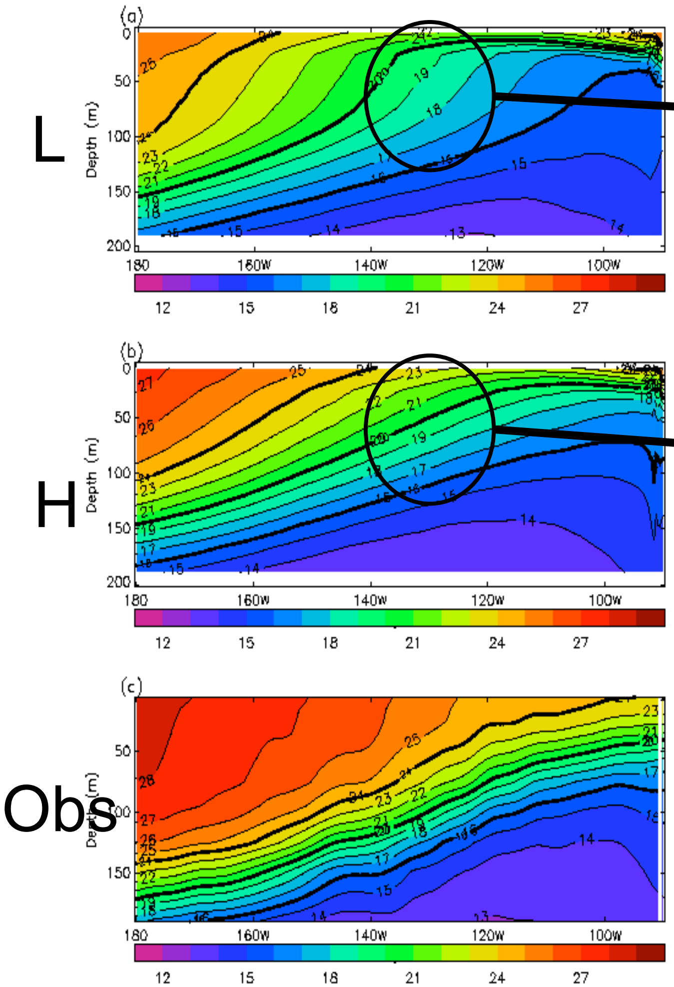
$1/3^{o}$ ocean



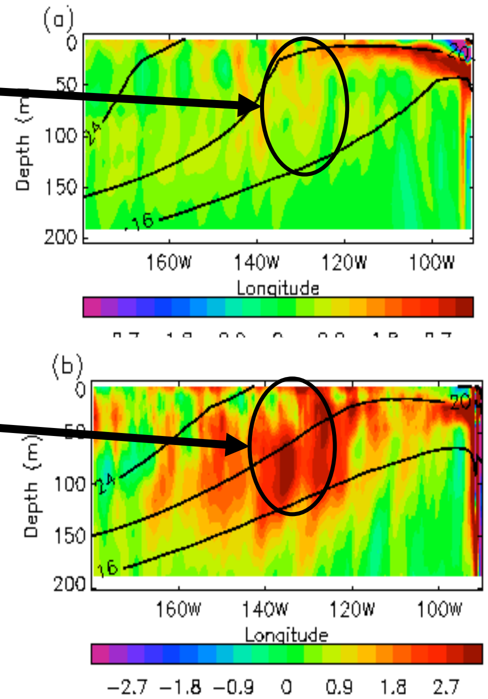
$1\text{-}1/3^{o}$ ocean

Shaffrey et al, 2009, J. Clim.

Eddies, SSTs and ENSO



Ocean temperature profile along Equator



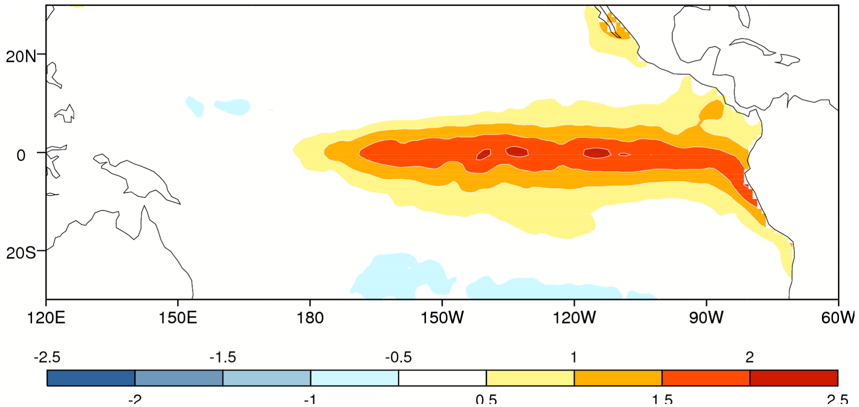
Eddy heat flux convergence

- Rôle of resolved versus parametrised ocean mixing, for example:
  - Tropical Instability Waves emerge in 90km-1/3° model (HiGEM), performing meridional mixing near Equator;
- ENSO is poorly represented in the standard Hadley Centre climate model (HadGEM1); a more realistic ENSO is simulated by the high-resolution HiGEM model;
  - is this because the HiGEM mean state in the tropical Pacific is so much closer to reality ?
  - if so, this is a good example of a smaller scale phenomenon affecting the large scale mean state and, through it, a major element of climate variability.

Roberts et al, 2009, J. Clim.

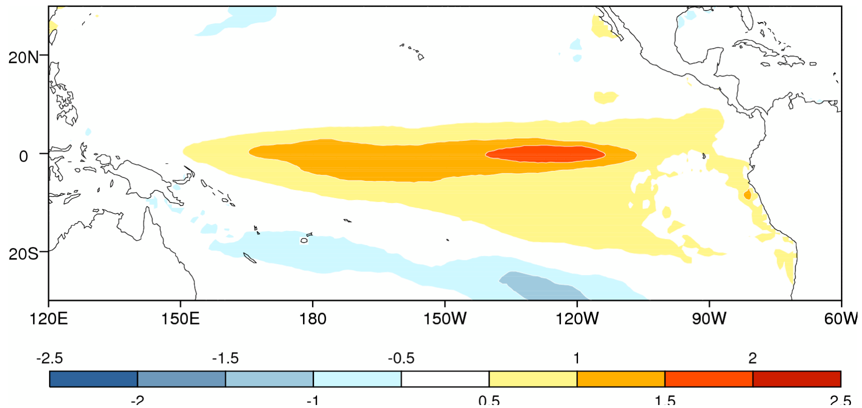
El Nino in HiGEM

Observations (HadISST2)



El Nino DJF Sea Surface Temperature composites from HadISST2, HadGEM1.2 and HiGEM1.2. Units K

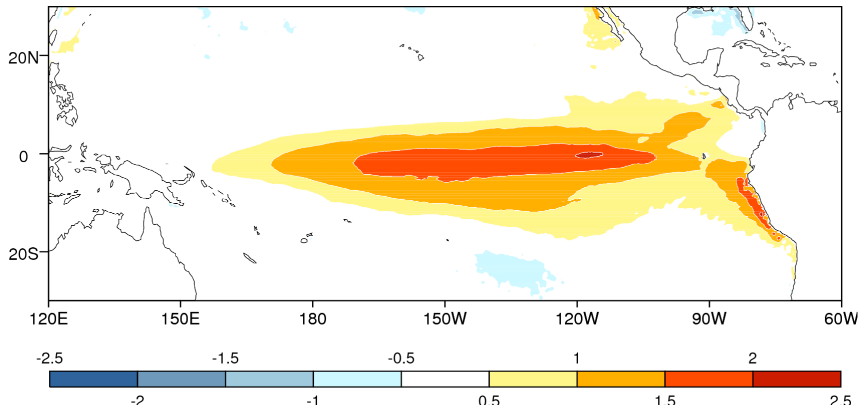
HadGEM1.2



133 years climatology

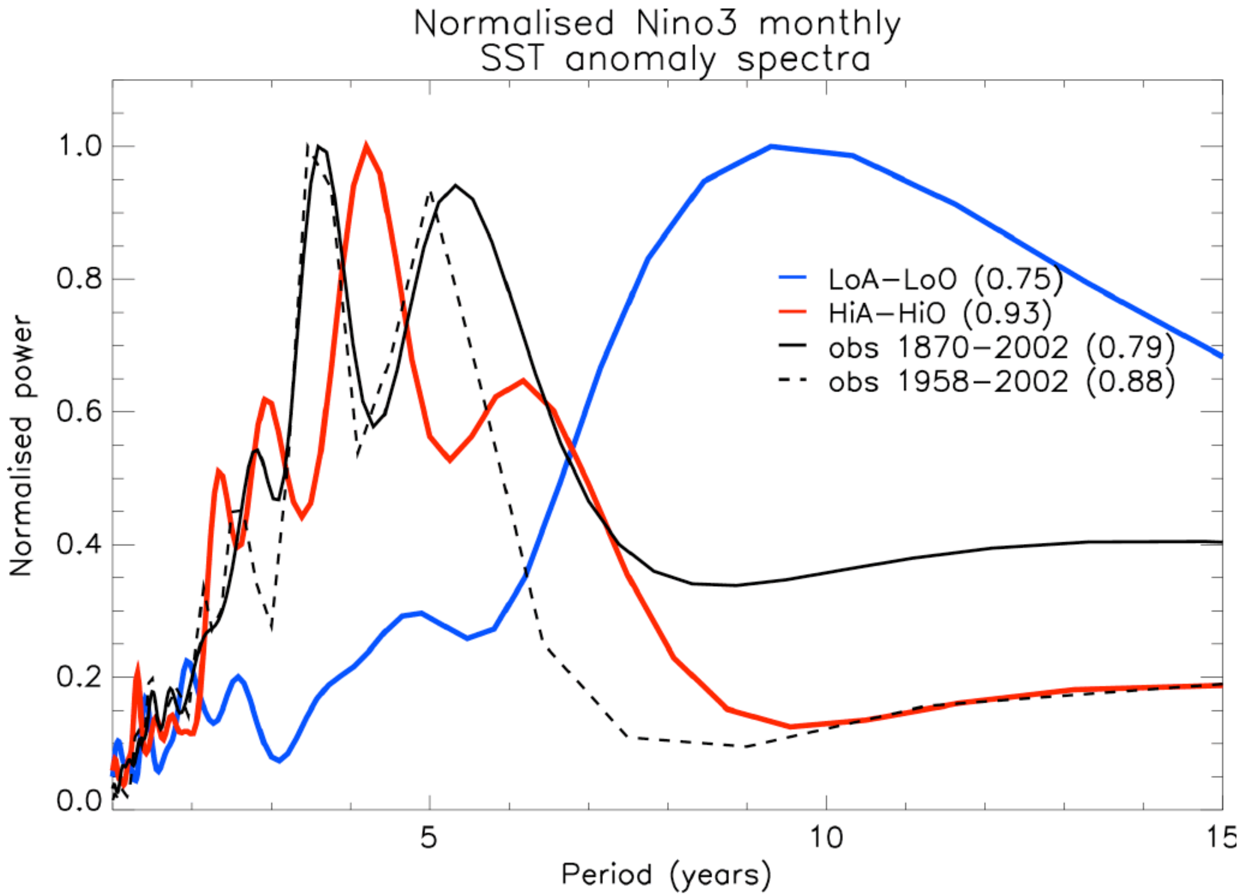
The warming of the Tropical Pacific during an El Nino event is well captured in HiGEM.

HiGEM1.2



•This source of natural variability affects the distribution and number of TCs …

El Nino in HiGEM



Normalised Nino3 SST Power Spectra for HadISST, HadGEM1.1 and HiGEM1.1

Both the spatial and temporal characteristics of ENSO, and its remote teleconnections, are better simulated in HiGEM relative to HadGEM

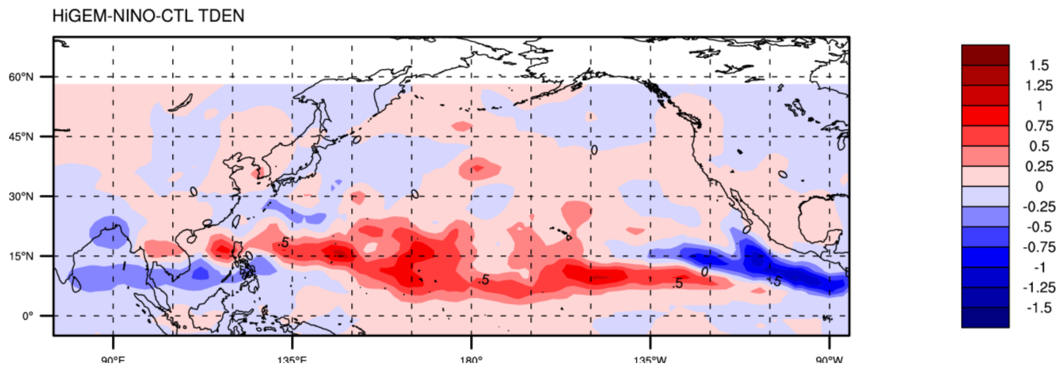
Why does the ENSO improve in HiGEM?

Shaffrey et al, 2009, J. Clim.

Impact of natural variability on simulated tropical cyclones

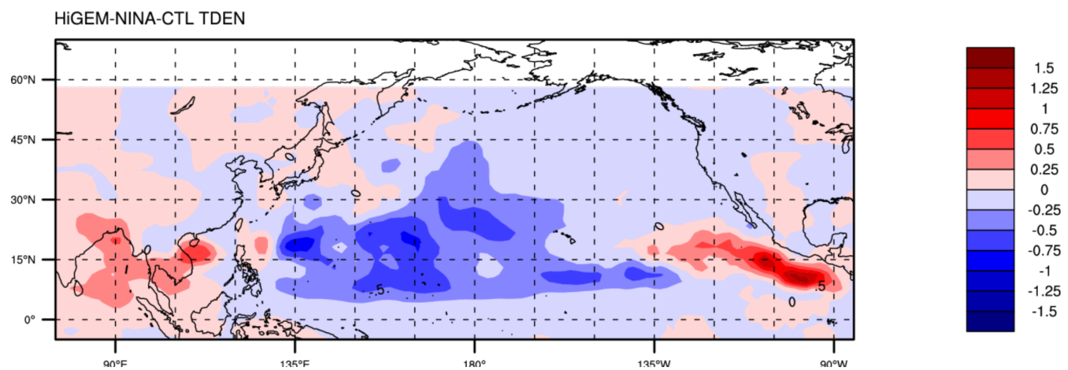
Niño-CTL TCs from 133 years of HiGEM

NH TC track density (May-Nov)



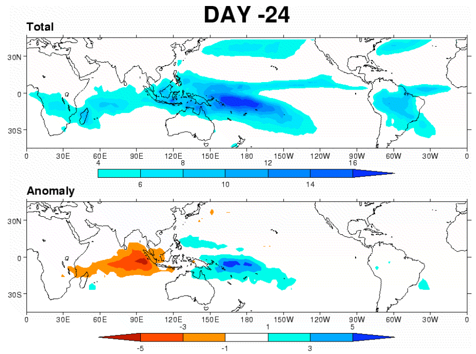
Niña-CTL TCs from 133 years of HiGEM

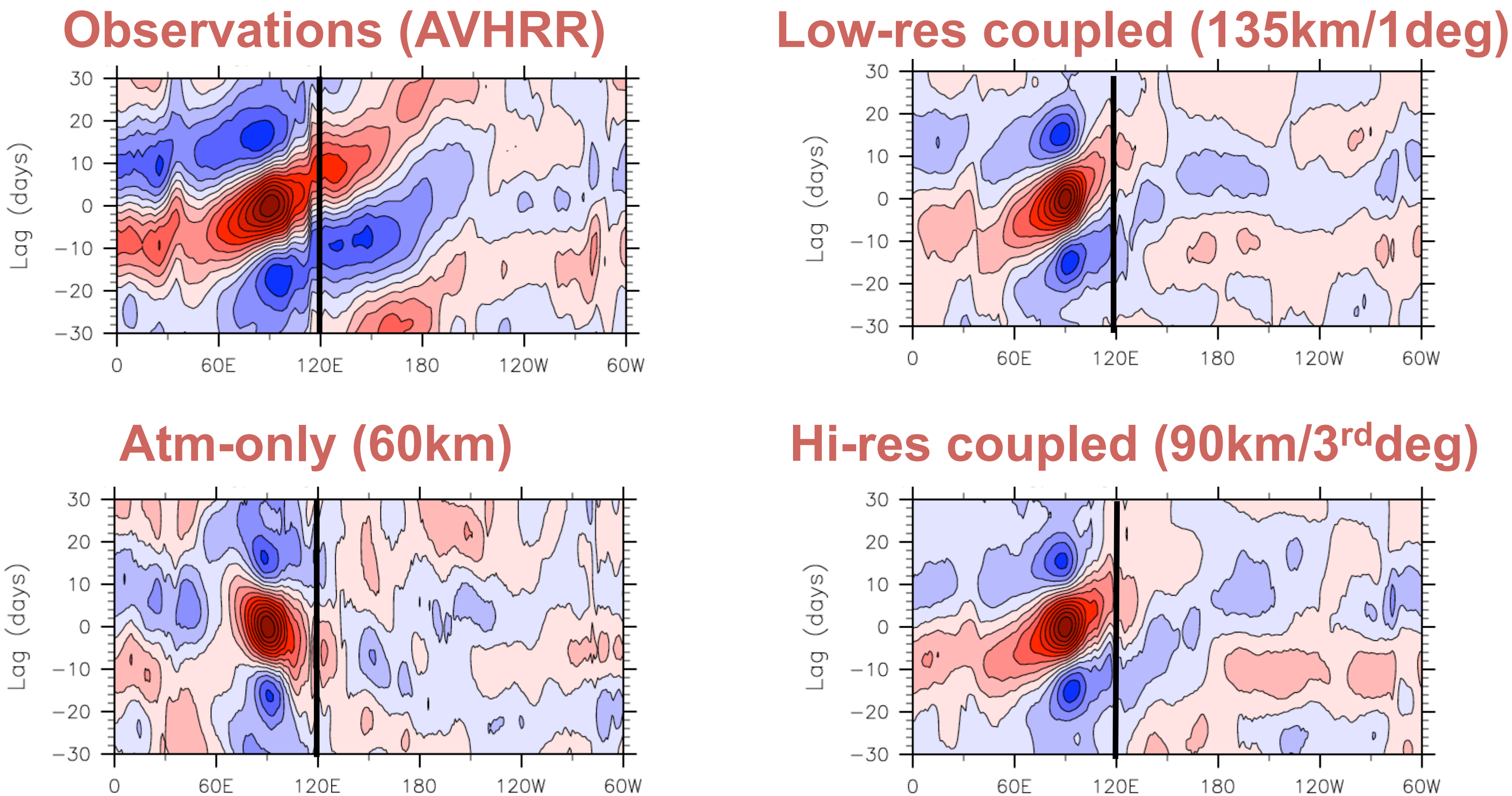
NH TC track density (May-Nov)



- HiGEM has significant skill at simulating El Niño and La Niña conditions
- Under El Niño (La Niña) conditions, there is an eastward (westward) shift in tracks to the central Pacific Ocean (East Asia)
- Improving understanding of the impact of natural variability on TCs, may provide an element of (short term) predictability if we know the background state of the climate

Madden-Julian Oscillation (MJO)





Propagation of MJO convection along the equator

OLR (5N-5Savg, 20-100days, Oct-Apr): Lag autocorrelation with 90E value

A. Clayton

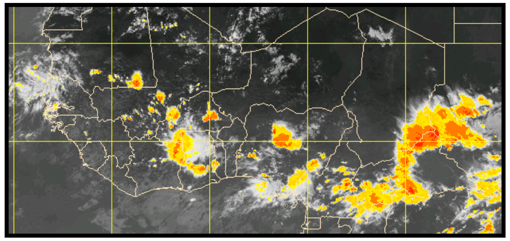
Frontiers of model development: Cascade

Scale interactions in the tropical atmosphere, S. Woolnough et al.

Case Studies

West Africa

• African Easterly Waves

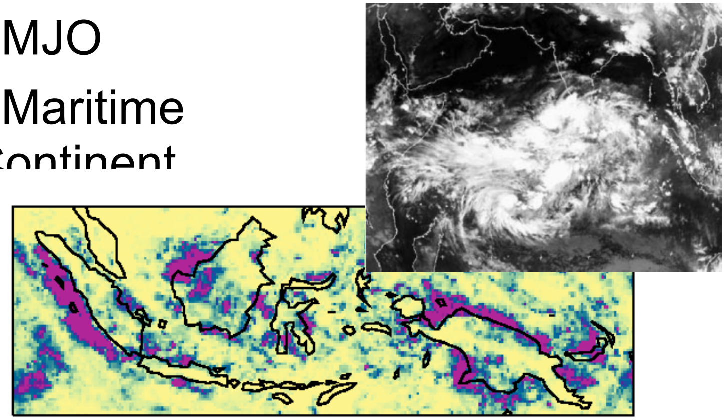


Warm Pool

• MJO

• Maritime Continent

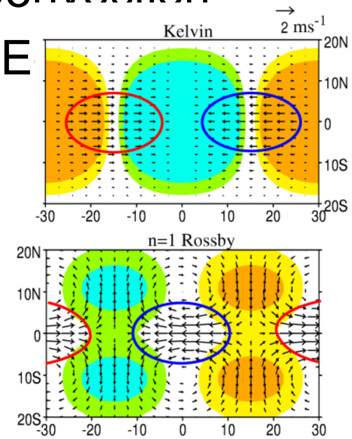
•



Idealised

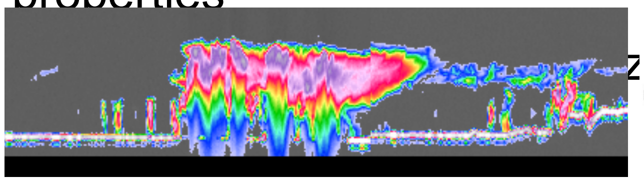
• Warm Pool Convection

• E s

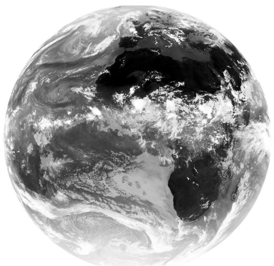


Model Evaluation against Observations

• CloudSat/CALIPSO: vertical cloud properties



z

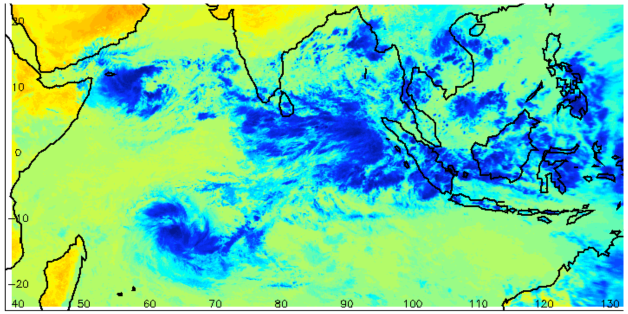


Synthesis

- Analysis of scale interactions
- Insight into physical processes
- Compare with climate / NWP resolution
- Conclusions for parameterization

Comparison with hi-res (5 km) satellite data Oct. 19

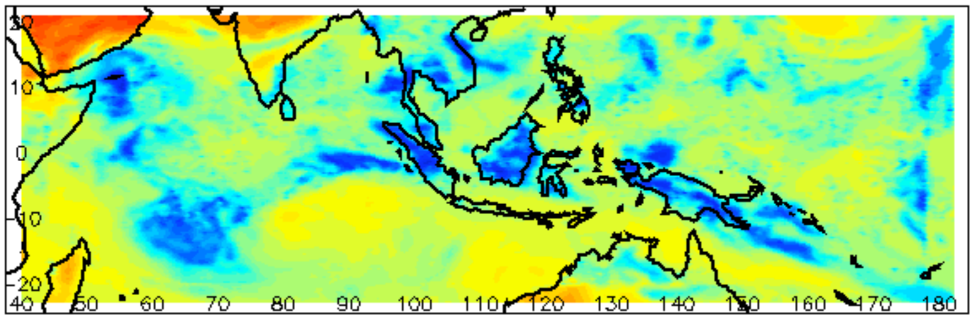
Observations:



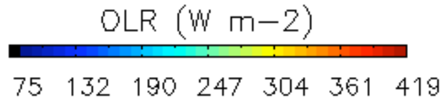
Models capture tropical cyclones in western Indian Ocean, but not the generation of deep convection in the eastern Indian.

globLAM: days since 2008-10-09 00:00:00: 10.35

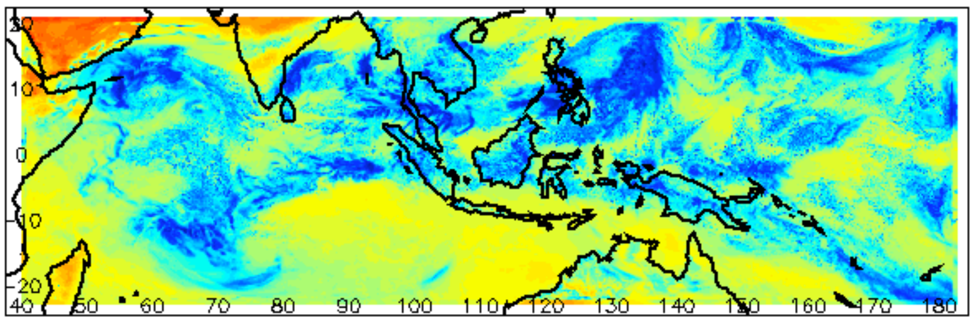
40x60 km grid:



12km:



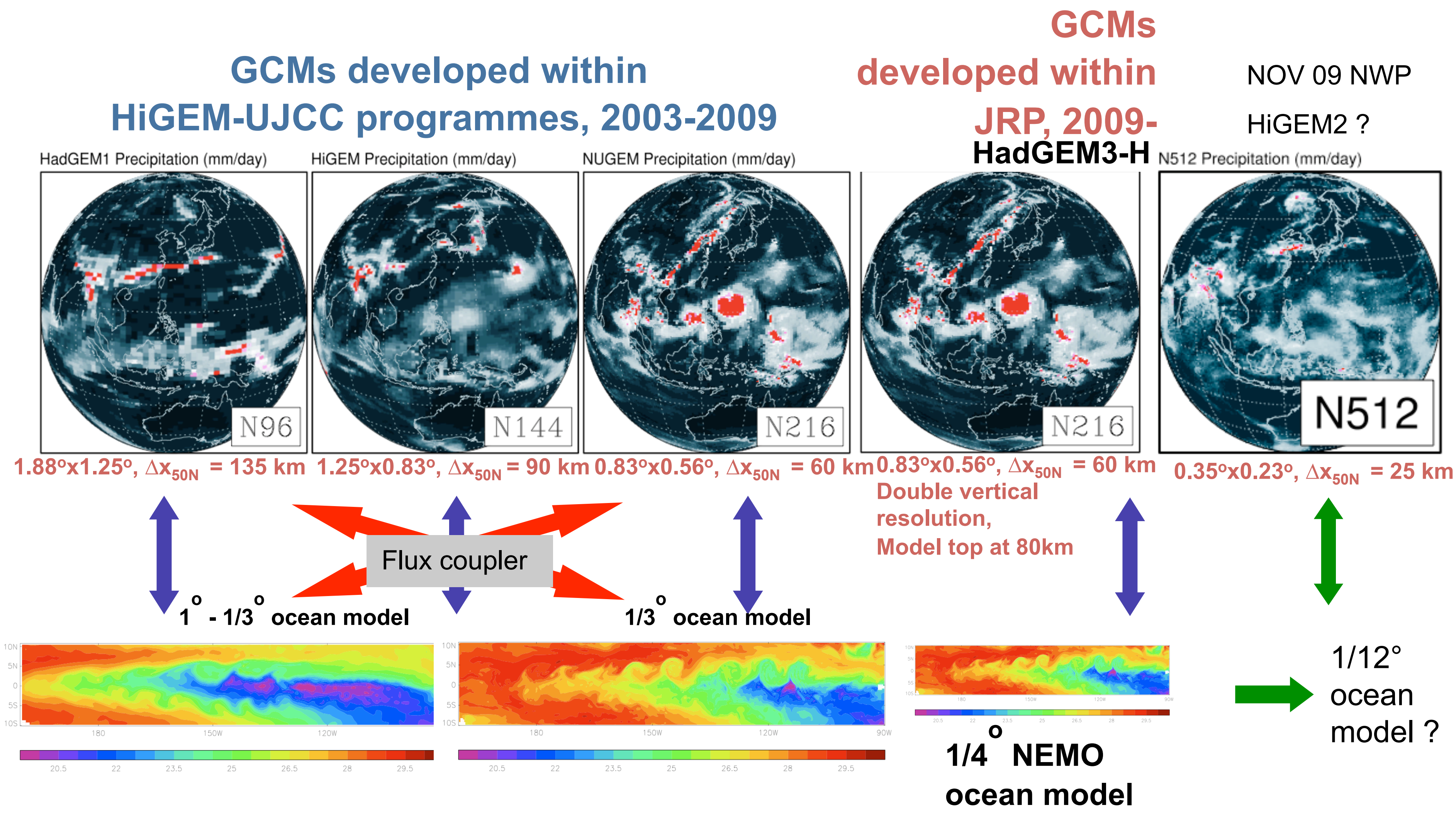
12 km grid:



C. Holloway, see his poster

From UJCC and HiGEM to the Met Office – NERC

Joint Research Programme (JRP)

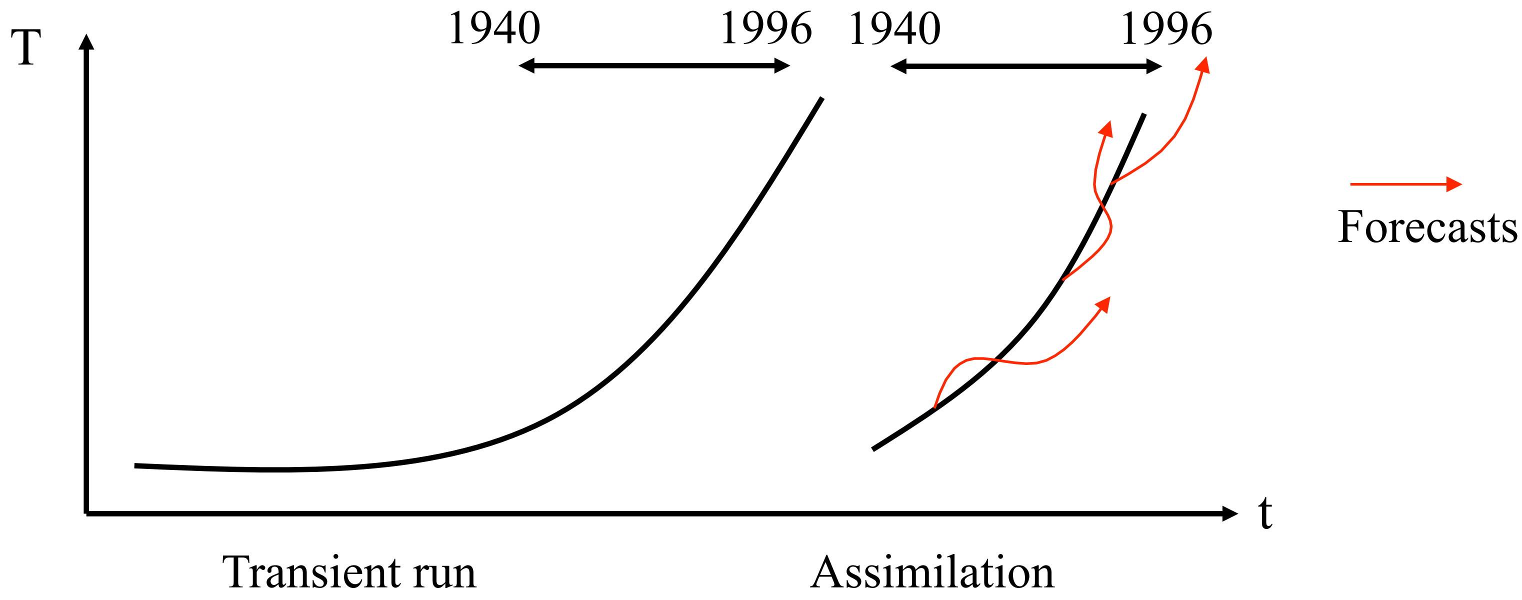


Climate predictability and prediction

HiGEM Decadal Predictability Experiments

Shaffrey, Hawkins, Sutton, Smith, Vidale,

- We will provide near-term, decadal predictions using HiGEM to the CMIP5 near-term climate change experiment
- HiGEM is highest-resolution coupled model used for DP in CMIP5
- Implemented a methodology based on DePreSys, an anomaly assimilation scheme which Doug Smith developed at the Met Office



- Spin-down experiments completed;
- Anomaly assimilation technique tested and implemented;
- First hindcast test runs progressing

Summary

- Current (IPCC AR4) global climate models lack many of the skills required to answer societal needs for predicting climate risks and their attribution at the <u>regional scale</u>;
- Presented a model hierarchy, comprising grid spacing between:
  - 270km and 60km in the atmosphere
  - 1-1/3^{o} and 1/3^{o} in the ocean
- Cyclones emerge at all scales, but their intensity in sensitive to (increases with) resolution
- The coupled model (HiGEM) reveals some interesting scale interactions:
  - between TIWs and equatorial Pacific SSTs, which help to support a more realistic ENSO;
  - between ENSO and tropical cyclones
- Our datasets are useful tools to understand climate and its variability:
  - globally consistent synthetic data sets, traceable in terms of mechanisms
  - global information at scales that start to be appropriate for regional impacts studies
- Our participation in the next IPCC, with the submission of near-term, high-resolution decadal predictions to CMIP5, embodies the essence of UJCC and HiGEM, marking the shift to a new level of collaboration between NERC and the Met Office, under the auspices of the Joint Climate Research Programme (JCRP).

A prototype model hierarchy

Groups involved

SIMA + specialists

QUMP, Mitigation, Dangerous CC

Ultra high resolution
- Groups involved: Met R&D, CASCADE, Earth Simulator Centre
- 'Global' Atmosphere (N320, CASCADE, …)
- Reduced domain (RCM, NAE, CAM, UK4, 1km)
- → Targeted expts with specific processes

Seasonal/Decadal
- Groups involved: UJCC, HiGEM, seasonal
- Global OAGCM (N216,0.25° L85)
- Run for multidecades on joint supercomputer
- Balanced/tuned climate NOT required
- → Operational Seasonal and Decadal Forecasting

Centennial/Ensembles
- Groups involved: Model development teams
- Global AOGCM (N144/N96,0.5°/1° ?)
- Multiple multicentury runs or S2D ensembles
- Needs balanced/tuned climate simulation
- → A few scenarios with large range of processes
- QUMP

"Physical traceability barrier"

Earth System
- Groups involved: QUEST
- Global AOGCM (N48, 2°)
- Large multicentury ensembles, rapid response
- Needs balanced/tuned climate simulation
- → Complexity-QUMP

Simple model
- Groups involved: MOHC specialists, academics
- EMIC, EBM, statistical emulator, empirical f/c model, statistical downscaling, …
- Producing pdfs, Low prob events, rapid response
- → Unrestricted processes (parameterized)